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AGARD CONFERENCE PROCEEDINGS No.495

Progress in Military Airlift

(Les Progrès Réalisés dans le Domaine du Transport Aérien Militaire)

DISTRIBUTION STATEMENT A
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TITLE: Progress in Military Airlift: The Flight Mechanics Panel Symposium Held Lisbon, Portugal on 28-31 May 1990 (Les Progress Realises dans le Domaine du Transport Aerien Militaire)

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Published December 1990

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ISBN 92-835-0585-9

*Printed by Specialised Printing Services Limited
40 Chigwell Lane, Loughton, Essex IG10 3TZ*

AGARD-CP-495

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Conference Proceedings No.495

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Papers presented at the Flight Mechanics Panel Symposium held in
Lisbon, Portugal from 28th to 31st May 1990.

Preface

Military transport aircraft and helicopters will continue to be of increasing importance in future military operations. Due to economic constraints, military transport aircraft technology has not received the same level of attention that has been directed, for example, to combat aircraft. In-service fleets of transport aircraft are also becoming physically old and technically outdated, and are less and less capable of fulfilling the more demanding mission requirements.

It was therefore considered important and timely to review this area and assess:

— The present and perceived future military roles and requirements for airlift;

— The developments in technology necessary to fulfill the requirements;

— The extent to which technology developed for civil applications can enhance the capabilities of military transport aircraft and helicopters;

— The kind of technology that can bring real cost reduction; and

It was also considered important to review the current and future development programmes in this field, and assess to what extent they embody the new technologies.

A Symposium sponsored by the Flight Mechanics Panel of AGARD was seen as the best way of examining some of these aspects. The Symposium included sessions on operational experience and requirements; cockpit design and aircrew performance; specific technologies such as fuel, powerplant and aerodynamic design; and a review of current and new programmes. (25) * Military aircraft, * Transport aircraft, * Helicopters, airlift operations.

Préface

Il y a tout lieu de croire que l'importance croisante que est accordée aux aéronefs et aux hélicoptères de transport militaires sera maintenue lors des opérations militaires futures. Jusqu'ici, en raison des contraintes économiques, les technologies entrant dans la construction des aéronefs de transport militaires n'ont pas suscité le même intérêt que celles employées pour les avoins de combat par example.

Les flottes d'avions de transport qui sont en service à l'heure actuelle sont vieillissantes, techniquement démodées et de moins en moins aptes à répondre aux exigences de certaines missions difficiles.

Il a donc été considéré comme nécessaire et opportun d'examiner l'état actuel des connaissances dans ce domaine, ainsi que d'évaluer:

— le rôle militaire présent et future et les spécifications du transport aérien militaire.

— les développements dans les techniques nécessaires pour répondre à ces spécifications.

— la mesure dans laquelle les technologies développées pour des applications civiles peuvent servie à augmenter les capacités des avions et hélicoptères de transport militaire.

— les technologies susceptibles d'amener une véritable réduction des coûts.

Il a également été considéré comme important de faire le point des programmes de développement actuels et projetés dans ce domaine, et d'estimer leur contribution potentielle pour des technologies nouvelles.

Le Panel AGARD de la Mécanique de Vol, a décidé que l'organisation d'un symposium fut l'une des meilleures voies pour examiner certaines de ces questions.

Le symposium comprit des sessions sur les spécifications et l'expérience opérationnelles, la conception du poste de pilotage et les performances des équipages, les technologies employées dans des domaines spécifiques tels que les combustibles, les propulseurs et la conception aérodynamique, ainsi qu'un résumé des programmes en cours et prévus.

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ACKNOWLEDGEMENT

The Flight Mechanics Panel wishes to express its thanks to the National Authorities of Portugal for the invitation to hold this meeting in Lisbon, and for the facilities and personnel which made the meeting possible.

Le Panel du Mécanique du Vol tient à remercier les Autorités Nationales du Portugal pour leur invitation à tenir cette réunion à Lisbon ainsi que des installations et du personnel mis à sa disposition.

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KEYNOTE ADDRESS

by

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Before beginning this address, I wanted to make one or two points about my credentials. Although I was the senior officer involved in airlift operations at SHAPE until a few months ago, and remain very interested in the future employment and applications of air transport forces, I am now working in an entirely different field (arms control) at NATO HQ. Accordingly, I shall not be expressing an official NATO view this morning but only a personal opinion from the perspective of my current position in NATO.

We stand today at one of the major crossroads of history. After more than four decades of facing up to the threat from a Soviet-led Warsaw Pact, whose offensive posture has been only too obvious, NATO suddenly finds itself confronting an altogether different challenge - a challenge which requires the Alliance to maintain a credible strategy against a rapidly changing background of international relations. Since airlift missions are always conducted in support of other military tasks, and since airlift concepts of operations can never be divorced from overall defence policy, I thought I should begin my remarks to this important and timely symposium by commenting upon the remarkable changes which are beginning to transform the politico-military landscape.

As you know, the tempo of change has been truly breathtaking. In the space of just a few short months, which will probably come to be seen as one of the most significant periods in this or any previous century, the political climate has changed almost beyond recognition. To continue with the meteorological analogy, the cold front and associated depression which has dominated the political weather in Eastern Europe for so long is rapidly giving way, under high pressure, to anticyclonic conditions, and the long-term outlook calls for "Open Skies" and good visibility. Of course, the impact of these changes has not been confined to Eastern Europe, where progress towards democracy has developed an unstoppable momentum. Here also in the West the nature and pace of those profound changes, coupled with the radical policies now being pursued by President Gorbachev, have had a tremendous impact on political and public opinion alike. As a result, all Alliance governments have become committed to seeking (and in some cases to demanding) significant arms reductions and an appropriate re-shaping of NATO roles, strategies and capabilities.

Even as recently as last autumn, no-one could have predicted the extent to which political and public perceptions and expectations would become so dramatically transformed over a period of only a few months. That said, the NATO Alliance has long recognized that the world has far too many weapons and has for many years tried to achieve international stability and security at a much lower level of forces than those currently deployed in Europe. Now, as a result of developments in Eastern Europe, plus our massive investment in building up and maintaining a strong defence over the past four decades, we are on the brink of achieving this hitherto elusive goal.

Following the treaty on intermediate nuclear forces signed in December 1987, it now seems certain that Presidents Bush and Gorbachev will sign another on reductions in strategic nuclear systems within the next few days. Meanwhile, the negotiations on reductions in Conventional Forces in Europe - better known as the CFE talks - continue in Vienna and will hopefully culminate in a formal treaty before the end of this year. It is worth noting that the CFE negotiations are addressing reductions (within continental Europe from the Atlantic to the Urals) in the following specific categories:

* Main battle tanks
* Armoured combat vehicles
* Artillery
* Combat Fixed-Wing Aircraft
* Combat Helicopters
* US and Soviet stationed troops

Agreed figures for each category are still subject to negotiation but the key objectives remain clear:

* To establish a stable balance of conventional forces at lower levels than those currently in place.
* To eliminate imbalances which could be prejudicial to stability and security.
* To eliminate the capability for launching surprise attacks or large-scale offensive actions.

For various reasons, progress in Vienna has been rather disappointing in recent weeks but, given sufficient high level political direction - and both President Bush and President Gorbachev seem equally determined that the arms control process should continue on its successful path - there is every reason to assume that the problems will be resolved. Accordingly, most analysts expect a CFE treaty to be signed later this year, covering some or all of the weapon systems I mentioned a few moments ago.

So much for the background. The question we must address, in the context of this symposium, is "What are the implications for military airlift capabilities and concepts of operations?" Make no mistake; there will <u>be</u> implications. For example, no-one seriously doubts that military expenditure will be reduced to a greater or lesser extent in all Alliance states in an attempt to obtain, and to be seen by the voters to obtain, the so-called "Peace Dividend". In some countries, the government (or opposition party, if elected), is already committed to making large reductions in defence spending at the earliest opportunity. In others, the government may prefer to hold budgets at approximately current levels in cash terms, whilst allowing them to decay in real terms due to the corrosive effects of inflation. But however the reduction is achieved - whether overtly or by stealth - the net effect will be the same. Even after allowing for savings resulting from the reduced numbers of tanks, artillery and other weapon systems - and remember that these savings will probably be largely offset by the costs of the associated destruction and verification regimes, especially in the initial years of CFE implementation - there will not be enough money to sustain the remaining elements of the inventory at existing levels. Almost certainly, events will then follow an all-too-familiar course. Defence commitments and capabilities will be reviewed; priorities will be re-assessed; and hard decisions will have to be taken on which capabilities must be preserved and which capabilities should be sacrificed to allow those others to be retained. Many of you at this symposium, regardless of nationality, will remember what has happened in the past when budgetary pressures have forced governments and Ministries of Defence to identify candidates for savings. All too frequently, military airlift has been assessed as "nice to have" but not sufficiently vital to retain when forced to compete for scarce funds with other military priorities and capabilities.

Please don't misunderstand me. I am not saying that air transport forces will on this occasion have to bear more than their fair share of the coming "pain and grief". I am merely drawing attention to the obvious fact that, despite their many qualities and advantages (to which I will return in a few moments) airlift forces are always likely to be vulnerable to excessive pruning when military budgets are squeezed hard. As far as I know, neither NATO nor National Defence staffs have yet had a chance to study the strategic implications of arms control and budget reductions, much less the more detailed questions of doctrine, concepts and posture. Events have simply been moving too fast. In any case, it makes sense to adopt a cautious and measured approach. Before deciding if, how and when its defence policy should be revised, the Alliance needs to await the outcome of the CFE Treaty, monitor events in the USSR over a longer period, and satisfy itself that a unified Germany will be firmly embedded within NATO.

Nevertheless, we now know that policy and strategy reviews will take place within the foreseeable future at both the national and international level. Assuming that a worthwhile CFE treaty can be signed, complemented if possible by a comprehensive package of Confidence and Security Building Measures, the Soviet Union's posture west of the Urals will lose much of its potential for large-scale offensive action. At the same time, the emergence of truly independent governments in Poland, Czechoslovakia and Hungary will create a buffer between NATO territory in central Europe and the Soviet Union, and thereby further reduce the USSR's capacity for surprise attack.

But, as you know, the political and economic situation inside the USSR is likely to remain extremely grave for some time to come as Gorbachev struggles to implement his reforms while trying to avoid presiding over the break-up of the Soviet Union as one republic after another queues up to demand independence from Moscow. Such an unstable and volatile situation in a state which is as militarily powerful as the USSR is fraught with danger, and it would therefore be folly for the Alliance to lower its guard too soon. With that in mind, and assuming that arms reductions are implemented more or less as planned, I believe that military airlift could and should attain not a lesser but a greater importance in any future spectrum of western defence capability.

My rationale for this assertion is as follows. First, let us consider the future situation within Europe. Force levels on both sides will be reduced, the Soviet posture will become less threatening and warning time of any Soviet aggression will increase. However, the simple facts of geography mean that the USSR will still be able to deploy forces from East to West more rapidly than the USA and Canada can deploy reinforcements across the Atlantic. In view of the slow speed of ships and their vulnerability to various forms of interdiction, it will therefore be vital for NATO to retain a dedicated force of airlifters that can deploy large numbers of key personnel and urgent supplies to Europe from North America within a relatively short timescale.

The advantages of reach and rapidity of response over vast distances - which only airlift can provide - were clearly demonstrated during the Arab/Israeli War of 1973. Although this was rather a short war, it was over by the time the first logistic supplies arrived in Israel by sea from the USA. Meanwhile, the USSR had airlifted 15,000 tons of supplies to Egypt and Syria, and nearly twice that amount had been flown into Israel by a combination of civilian and military air transport assets.

One could, of course, cite many more examples from the post-war era in which airlifters (both fixed and rotary wing) have repeatedly moved troops, equipment and logistic supplies over distances, terrain and within timescales that would have been impossible by any other means. In fact, during the 40 years since the Berlin Airlift (1948/49) - an operation which above all others demonstrated that air transport forces could be a powerful factor in the application of political as well as military pressure - all major powers, and many lesser ones, have come to recognize that, in the final analysis, a sovereign state must be ready and able to use force in defence of its vital interests. If, when these interests are threatened, sufficient forces are not already in place, they must be deployed quickly to where they are needed. Frequently, the time factor will be critical, in which case only airlift will suffice.

What I am saying, of course, is that airlift already is - and will continue to be in the new era of arms reductions - a major instrument of deterrence and force projection. Neither army nor air combat units can realise their full potential unless they can be rapidly deployed to where they are needed. This is not to say that forces can be quickly deployed only by air; in some cases, involving distances of just a few hundred miles, it may be almost as fast and certainly more cost-effective to deploy by truck or train if suitable roads and railways are available. Moreover, airlift can never compete in terms of payload with the massive capacity of a good railway system or fleet of cargo ships. On the other hand, it remains a basic fact of military life that force projection can seldom be achieved without recourse to at least some airlift.

For example, we all know that fighter aircraft cannot operate effectively away from their home base without groundcrew, specialist equipment and weapons. Most if not all of this logistic support must be airlifted if the inherent speed and flexibility of the combat aircraft themselves are not to be degraded. Even after the CFE treaty is signed, there are still likely to be thousands of combat aircraft on both sides and they will still need to exercise frequently - sometimes at great distances from their home bases. Thus the continued existence of airlift (and, where appropriate and available, tanker/transport support) will be crucial to the training needs and operational credibility of many alliance combat aircraft units.

As for the role of ground forces in the new era, I see no reason to change my view that armies enjoy full credibility only if they are able to deploy rapidly from their peacetime bases to wherever they may suddenly be needed - both within the future European theatre and in other parts of the world. Conversely, ground forces which cannot call upon at least some dedicated fixed-wing and helicopter airlift are certain to lack reflexes and mobility, and as a result may be powerless to invervene effectively in situations where, with the benefit of air mobility, they might otherwise be able to play a decisive role.

Perhaps at this point I can draw your attention to the distinction between rapid reinforcement (entailing the deployment of forces by air to strengthen an existing base or garrison) and the wider concept of using airlift to intervene in areas where there may previously have been no military presence. Although the ability to undertake rapid reinforcement operations offers a variety of political, operational and economic advantages - especially in the future when NATO strategy will probably rely even more heavily on reinforcements than it does today - the capacity to insert forces by air whenever and wherever they are needed is arguably more important. Although prospects for peace in Europe have never been better, there are other areas of the world - notably the Middle East and some parts of Africa - which remain dangerously unstable. Currently, the West has little or no permanently-based units in those areas, but who can say when we might need to apply some military pressure? It is another reality of politico-military life that early deployment of even a modest force can often defuse or stabilise a potentially dangerous or deteriorating situation.

I would also contend that the possession of even a limited air transport capability - which is to say enough airlift to apply at least some measure of force - will confer advantages out of all proportion to the resources involved. NATO's ACE Mobile Force (or AMF) is an excellent illustration of this concept. As you probably know, the AMF is a lightly-armed, brigade-sized multinational force which is intended to reinforce deterrence in a threatened area by demonstrating NATO resolve and solidarity. In order to be in place in time to achieve this objective, the AMF must move with great speed to its deployment areas on the flanks from its dispersed locations on both sides of the Atlantic. This means that it must rely heavily upon air transport. We may expect the same principle to apply to any additional multinational mobile forces which the Alliance may decide to establish in the coming years.

In summing up, I would like to leave you with the following key points:

1. First, the implications of the probable reductions in some categories of conventional forces have yet to be fully addressed. Until the necessary policy studies have been initiated and completed, it is impossible to estimate the impact on national postures and inventories.

2. Second, it is reasonable to assume that military budgets will eventually be reduced and that airlift forces may once again prove vulnerable. This has already happened in the USA where the planned procurement of C-17s has been cut back by fifty per cent.

3. Third, I believe that excessive cuts in airlift capability would be undesirable because air mobility is likely to assume greater importance as NATO moves towards greater dependence on reinforcement, and as some Alliance members look increasingly to their individual and collective interests outside the NATO area.

As we all know, airlift operations do not enjoy the glamorous image of the combat-orientated roles, but they do share the classic air power attributes of speed, reach and flexibility and, more importantly, they confer these same qualities upon the forces which they carry and support. Hence it is not surprising that, within the space of only a few decades, airlift operations have come to occupy a pivotal role in the projection of military power - whether at the strategic, tactical or battlefield level.

Of course we would all acknowledge that there are limitations to what air transport operations can achieve, due to such factors as aircraft capacity and performance, and the availability of suitable airfields in the right locations. We also recognise that airlift is an expensive asset for which demand is always likely to exceed supply. Nevertheless, it remains my basic thesis that only airlift can provide the rapid response which is so essential if force is to be applied in time to deter, counter or defeat aggression. To me, it seems self-evident that both fixed and rotary wing airlifters will remain a basic and indispensable instrument of defence policy and power projection. I also believe that the operational posture, reflexes and credibility of Alliance forces will continue to be significantly enhanced by the extent to which their key components can be airlifted.

THE STUDY APPROACH AND PERCEIVED NEEDS FOR AN ADVANCED THEATER TRANSPORT

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SUMMARY

The Advanced Transport Technology Mission Analysis (ATTMA) is a broad based investigation of future tactical airlift mission requirements and of the attendant technologies necessary to satisfy those requirements. The ATTMA study is a joint Aeronautical Systems Division, Deputy for Development Planning (ASD/XR) and Wright Research and Development Center, Technology Exploitation Directorate (WRDC/TX) initiative. This paper addresses the approach taken in the study effort and the perceived needs for a 21st century Advanced Theater Transport (ATT). The descriptors "theater, tactical, and intratheater" are used synonomously in this paper and are to be differentiated from a "strategic" or "intertheater" airlifter.

Specific military airlift tasks are defined in detail for Europe, Southwest Asia, and Central America that are representative of the kinds of missions that we believe will drive the demand for theater airlift in the 21st century. ~~These tasks then serve as a basis for comparing the productivity/effectiveness of alternative system options.~~ Presented are the results of conceptual STOL and VSTOL airlifters relative to the current US airlift fleet in accomplishing the tasks defined above. Perceived system deficiencies and corresponding needs are identified. One such need is improved cargo handling (loading/unloading and transshipment) for future theater airlifters operating into short, austere landing sites in or near a threat environment. When one considers the many variations in intermodel interfaces with present or future airlifters and the potential increase in the need for theater airlift ~~on an international~~ scale, the cargo handling issue may be one of several that could benefit greatly from international cooperation.

25 * Airlift operations; * Transport aviation; Theater level organizations.

INTRODUCTION

The US Army's evolving AirLand Battle doctrine features the concept of a non-linear battlefield where versatile and highly maneuverable fighting units are operating autonomously with largely non-existent or indefensible ground lines of communication. Prosecuting warfare under this concept may demand airlifters that are highly responsive, capable of operating into and out of an austere combat environment quickly. In examining the role of the future theater airlifter in this context, the mission analysis and technology planners at the Aeronautical Systems Division (ASD) embarked on a program of in-house and contracted mission analysis, technology application, and concept development to understand the key issues and to assess their impact on mission requirements and technology needs. The examination of future airlift needs is conducted in the context of three projected notional scenarios: the European Central Region, Southwest Asia, and Central America. The regions represented in these scenarios offer a diverse sampling of geographic features, infrastructure, climatic conditions, and threat intensities necessary for a comprehensive analysis.

With perceived changes in Fig 1 in the ways the US may be fighting future wars, study efforts were focused on the accomplishment of (1) a good understanding of the problem, (2) an analytical basis for establishing needs, (3) the identification of critical technologies, and (4) the identification of key system-level trade-offs.

To gain insights into the problem, let's look at current airlift capabilities shown in Fig 2. If the Continental United States (CONUS) is located on the lower left of this highly simplified chart and the combat arena on the far right, then we see theater airlift operations today and in the near-term, with the airlifters as shown. We can operate into and out of some of the forward operating locations (FOLs) and forward operating bases (FOBs) with runways at least 3000ft (900M) - 4000ft (1200M) long and that are in the Army's Corps rear. But from there, cargo for the Army must be transshipped forward as needed by available trucks, helicopters, etc. The big question here is, "Is this going to be good enough for the 21st century?"

If the Air Force is really serious about supporting the US Army's evolving AirLand Battle doctrine, then Fig 3 depicts the future role of theater airlift via the additional arrows. Here, the future airlifter is called upon to operate forward of the FOBs and FOLs and near and along combat areas. On occasion and under special circumstances, with external support, the airlifter may be required to enter combat areas. Further, as the Army concept of a non-linear battlefield evolves and becomes implemented, each aircraft mission flown in support of Army operations could occur in an active combat area. As a result, US airlifters may be required to fly in harm's way more than they have ever done before. Although not presented in this paper,

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considerable work in survivability was done to determine the goals for the needed survivability enhancements.

The theater transport of the future, as will be shown throughout the rest of this paper, may be called on to operate world-wide in a variety of climatic conditions ranging from the plains of Europe to the mountains of Southwest Asia to the jungles of Central America, against varying threats that are far more lethal than in the past. Operations into and out of remote and austere locations with unimproved runways, limited or non-existent landing aids, and in many cases, no material handling equipment will be required routinely.

APPROACH

The study approach in Fig 4 began with a "Needs Analysis." The Foreign Technology Division at Wright-Patterson Air Force Base developed a 20 year threat projection to airlifters in three scenarios, Europe, Southwest Asia, and Central America. The threat was documented and is updated periodically. Next, it was necessary to postulate a finite set of typical airlift tasks or jobs in each of the three scenarios for the 21st century. This was done with the help of Military Airlift Command (MAC) and the US Army and resulted in the identification of approximately seventy-five different cargo movement tasks or jobs that were representative of the nature and spectrum of interservice airlift tasks anticipated. These jobs constituted the "definition of the problem" or the jobs to be done by our airlift fleet. We next defined the baseline force in our airlift fleet as consisting of C-130Hs and C-17s. The deficiency analysis examined how well the C-130Hs and C-17s accomplished the set of jobs in the threat defined in each of the three scenarios. From this, system deficiencies were identified which in turn influenced system needs. Technology opportunities for ATTMA were examined by the Wright Research and Development Center to identify critical technologies that could be applied to system needs.

After the threat, the jobs, the baseline force, the deficiencies, and the technology opportunities were defined, members of the airframe industry (Boeing, Douglas, and Lockheed) were engaged to provide potential solution concepts sensitive to each of the elements in this approach. The solution concepts obtained were then evaluated by the Air Force to determine how well they performed relative to the baseline force in accomplishing the given job set in the presence of the projected threat. The General Research Corporation was an additional contractor engaged by the Air Force to provide specialized modelling and analysis support.

This complete cycle through the study approach has become known as our "First Iteration." Several of the following figures will amplify upon key elements of the study approach.

The representative airlift jobs fall into the five major categories shown in Fig 5; that is deployment, employment, retrograde, reconstitution, and alternate missions. In accord then with the way that a thirty day war builds up in each scenario and the way in which the combat areas were expected to move, specific cargo movements in the operations were defined in terms of the job characteristics shown. In defining and adding credibility to the jobs, operational airlift expertise was a necessity and this is where both MAC and the US Army were very helpful.

Thirty representative ATTMA jobs were defined for the European 30 day conflict. These jobs are highlighted in Fig 6 to illustrate the spectrum of tasks chosen. Although not shown specifically, all jobs are defined by closure time, movement priority, frequency of occurrence, size/weight, threat proximity, distance to delivery, etc. Closure time is the time required to deliver the total tonnage for a particular job. Priority relates to an operational determination of job importance. Frequency is how often the job occurs in a thirty day period. These parameters provide an indication of the detail necessary to define the jobs within a theater of operation.

Fig 7 presents bar charts of the tonnage distribution of the European jobs in Fig 6 by unit moves, emergency resupply, routine resupply, evacuation, and retrograde equipment. The frequency of occurrence of typical airlift activities and how they compare in total tons delivered are shown for a fixed level of tonnage delivered in a 30 day period. It can be seen that unit moves constitute 36% of the tonnage moved, whereas emergency resupply and routine resupply together makeup more than 50% of the tonnage.

It's also important to note that ATTMA is not just working the traditional airbase-to-airbase problem in theater airlift. We are concerned with where the job begins, where it ends, and the transportation modes and the infrastructure in-between. The intent is to minimize the travel time between entry and delivery sites and thereby enhance responsiveness. Fig 8 highlights the various delay points in delivering cargo from entry to delivery sites using a STOL or conventional aircraft. A VSTOL concept minimizes the delays in flying directly from entry to delivery points. One of the goals of this study is to quantify the differences between STOL and VSTOL airlift concepts.

The frequency and order of job occurrences are a direct function of force build-up and combat area movement in each scenario, and represent the cargo type, tonnage, and movement necessary to satisfy the theater airlift demand as a function of time. Fig 9 shows the demand function for Europe derived from the European job set shown earlier, and also includes similarly derived demand functions for Southwest Asia and Central America from their respective job sets. The functions are broken down into categories to illustrate the types of cargo to be moved. The categories are passengers (PAX), bulk, ammo, fuel, and vehicles. The breakdown offers insight into the nature of airlift requirements per theater. Also presented is the percentage of cargo delivered into and near the combat area. These demand functions are fed into a simulation of a 30 day war in each scenario and serve as a basis for comparing the productivity/effectiveness of alternative systems in a mixed force. It must be remembered that these demand functions are representative of the tonnages required in a portion of each theater and do not constitute total theater airlift tonnage.

CONCEPT DEVELOPMENT

As indicated earlier, study contracts with industry (Boeing, Lockheed, and Douglas) were initiated to obtain a data base describing a range of potential system concepts for a future theater airlifter. The selected configurations from those studies are presented in the matrix shown in Fig 10, by concept type, payload box-size, and contractor. The contractors were asked to look at not only STOL and VSTOL concepts, but also low observable versions of each. They were directed to begin with a C-130H box-size and to examine the range of payload variants from 25,000 lbs (11.36 Metric Tons or MTs) to 60,000 lbs (27.27 MTs). The elements in the matrix are lift-propulsion combinations of the concepts selected. For example, USB TF represents "Upper Surface Blowing - Turbo Fan;" EBF PF represents "Externally Blown Flaps - Prop Fan;" TP stands for "Turbo-Prop;" and the rest are self explanatory. Approximately one-hundred configurations were developed by the contractors and screened down to the 22 shown. A further screening by the Air Force resulted in a detailed in-house analysis of 16 final concepts.

The payload/range performance of the advanced concepts in Fig 10 is presented in Fig 11 for the purpose of comparison relative to the C-130H. The advanced concepts carry only internal fuel while the C-130H in the comparison requires external fuel also. The improved performance over the C-130H is largely a function of technology changes since the 1950s in areas such as materials, propulsion, lift devices, and fuels. The V-22 OSPREY performance envelope is included for additional comparison.

In addition to developing concepts, there is a need to measure their benefits/penalties throughout the development process. To this end, an airlift transportation model was devised for ATTMA and is called the Generalized Air Mobility Model (GAMM). Fig 12 illustrates the features, inputs, and outputs of the model. As a function of the 30 day war scenario, cargo movement requests from the demand functions are processed by the transportation model scheduler. The scheduler considers the available aircraft, cargo priority, and destination, and assigns aircraft to accomplish the delivery. The figures-of-merit illustrated as outputs represent those most commonly used herein, with many other outputs available also. The use of the model is analogous to controlling a taxicab system in one of our major cities where every cab is tracked by tail number and reports into a central command post on a regular basis to pick up new assignments and to report any problems. The survivability parameter for each aircraft configuration being analyzed is determined separately and input into the model. The model is capable of handling mixed fleet operations and was instrumental in producing the system comparisons to be presented next.

For the fixed fleet analysis results presented in Fig 13, the baseline for comparison is a mixed fleet of C-130Hs and C-17s. The fleet consists of 80 C-130Hs and 16 C-17s in both Europe and SWA scenarios, whereas there are 16 C-130Hs and 2 C-17s in the Central American scenario. The alternative concepts are similarly employed in a mixed fleet with C-17s, with a one-for-one substitution of ATTs for C-130Hs. The figure-of-merit in this illustration is percentage improvement in tons delivered-on-time relative to the normalized baseline. Three payload/box size variations are examined for each configuration. This analysis holds fleet size constant with productivity and cost being variable. For the European scenario postulated, the STOL configuration is most effective. However, box size does not appear to be a factor. The use of the C-17 in conjunction with the alternative concepts appears to compensate quite nicely for variations in ATT payload/box size. Examination of the effectiveness measure for Southwest Asia and Central America indicates quite a different story. Southwest Asia can be best satisfied by a large STOL or VSTOL because of large distances separting take-off and landing sites, relatively few airfields which are far apart, high hot conditions at many of the landing sites, and long transshipment distances over poor roads. Central America is best satisfied by a medium VSTOL aircraft because of short distances separating take-off and landing sites, an abundance of many very small air strips cut out of the jungle, and very poor roads for transshipment. These findings indicate that Europe may not be the scenario driving requirements for an ATT, and that C-17 allocation and usage are critical to the solution.

Another view of the problem is obtained by comparing the baseline with mixed fleets of alternative STOL concepts in Europe relative to equal effectiveness. Fig 14 demonstrates the equal effectiveness parameter, total tons delivered, for a number of fleet sizes. Fleet size is varied as a ratio of aircraft "X" and C-17 aircraft. Aircraft "X" represents the C-130H or one of the three boxsize/payload variants of the STOL ATT alternative concept. At a fleet size of 80/16, the baseline exhibits an 80% total tons delivered figure-of-merit. For the same fleet size, the alternative concepts achieve 100% total tons delivered. For equal fleet effectiveness, the alternative concepts achieve the 80% figure-of-merit with less than 1/2 the C-130H fleet size. The small box size concepts achieve 80% effectiveness at a fleet size of slightly greater than 30/6, the medium at approximately 25/5, and the large at slightly greater than 20/4. This analysis indicates that any of the STOL payload/box size alternatives can achieve acceptable effectiveness in the European scenario at greatly reduced fleet sizes relative to the baseline. The issue now becomes one of cost, C-17 utilization rate and availability, and the business strategy embraced by MAC.

NEEDS

The need for a future theater airlifter is based on support requirements of US Army doctrine, increasing obsolescence of our present tactical transport aircraft, a rapid advance in enemy threat capabilities, and the existence of exploitable technological opportunities capable of providing the means to counter current deficiencies. These are expanded upon as follows. (1) The Army's AirLand Battle doctrine and its emerging future operational concepts emphasize securing or retaining the initiative and exercising it aggressively to defeat the enemy. Tactical airlift is pivotal to support of the Army's rear, close-in, and deep operations, as well as Special Operations Force augmentation. Transshipment logistics are prohibitively expensive in this environment and must be minimized. To satisfy these future tactical airlift requirements, an airlifter must be capable of delivering essential cargo directly to the user without traditional airfield/cargo handling constraints. (2) The C-130 has been the primary theater airlifter since 1955. C-130 design did not envision today's emphasis on low-level flying, shortfield delivery requirements, greatly increased threat, etc. A need exists for a future airlifter that is affordable, reliable, supportable, maintainable, dependable, and available in present and future operating environments, especially with a non-linear battlefield. Consequently, unless that capability is acquired, present and future tactical airlift requirements cannot be met. (3) The present and future threat environment is far more lethal than that envisioned by designers of the current defenseless tactical airlifter. Present tactical airlift inadequacies and the increased enemy threat dictate a requirement for incorporating advanced survivability features that minimize threat exposure in the air and on the ground. This present threat environment coupled with enemy air defense advancements and predictions for future proliferation casts doubt on our ability to meet theater airlift demands without an enhanced capability. (4) Application of advanced technological features (i.e., vertical lift/advanced propulsions, low-observables, composite materials, etc.) will provide a quantum leap in capability to satisfy many aspects of the tactical airlift mission. Technological advancements focusing on rapid cargo onload/offload and aerial delivery improvements are of particular importance. Dramatic advances in cargo aircraft payload/field length performance, flight characteristics, aeromedical capabilities, survivability, maintainability, and cargo handling are achievable, and investigations of their applicability must be accelerated.

The needs stated above are general in nature and must be quantified. Through implementation of the ATTMA study approach presented earlier, a summary of the major "perceived needs" taking shape thus far for an advanced airlift system is presented in Figs 15 and 16. One of the key needs is a short field capability that can provide retail delivery into short austere landing sites that have little or no material handling support. Aircraft systems with short field capabilities from near-vertical operations to a 2000ft STOL capability are being examined. A corollary need for operations into austere areas is a landing gear with a soft field capability. Equally important for austere operations is the needed independence from external support for loading/unloading operations. A range of load/unload concepts is being investigated to perform the load/unload operations in minutes rather than hours. Similarly, we need to be able to convert from a cargo configuration to a medical evacuation configuration in minutes instead of hours. And finally, the most important need of all in today's austere defense budget is affordability. We must present the user with alternatives that are highly productive, low risk, and affordable. An aggressive goal to pursue is to maintain the $/ton delivered for the new airlifter equivalent or less than that of the C-130.

There isn't enough space in this paper to discuss all the "perceived needs." Suffice to say, the study is continuing with the intent to quantify as many needs as possible, to determine applicable tradeoffs, and to identify critical technologies.

FUTURE ACTIVITIES

Today's deficiencies in theater airlift productivity have been discussed throughout this paper and Fig 17 summarizes some of the key ones. Our airlifters today are as good as is the infrastructure they are operating in. With long, hard-surface runways, with many airfields, and with a good road structure for transshipment, we can demonstrate a reasonably good transportation capability with theater airlift. In a much poorer infrastructure, where most of our future conflicts may occur, or with a non-linear battlefield, today's system has limitations. Today's capability is also tied to the 463L Material Handling System, an aging and resource limited contingent of loaders and unloaders not very well-suited for operations in forward, austere environments. Today's airlift force is airdrop-capable; however, the airdrop function by its very nature is excellent for emergency situations but is a very inefficient one for sustained operations and creates a heavy training burden. Airland operations, if possible, are far more preferable.

As shown in Fig 18, today's deficiencies may be greatly reduced by building an airlift system that strives to become independent of the scenario infrastructure; that is, it has a short field capability and a soft-surface landing gear for getting into the short austere fields as close to the customer as possible. Once there, its quick self unload capability permits a rapid departure to escape attrition while on the ground. Because the system provides direct support to the customer, there is a great need for a good command, control, communications, and intelligence (C3I) link.

The thrust then for the future is to continue technology development, continue the development of system concepts and joint concepts of operation with the Army, improve our methodology for comparing alternative systems (improve GAMM to be sensitive to cargo handling constraints and C3I), and encourage opportunities for international cooperation.

Because of the importance of the cargo handling issue, which has been mentioned several times in this paper, it is the subject of an Air Force initiative urging international cooperation. The proposed plan for the study, scheduled to start yet sometime this calendar year, is presented in Fig 19. It begins with a determination of the cargo that must be moved under what conditions, how quickly and to where. Next, a broad range of solution concepts is explored to obtain an initial screening of feasible concepts. Those with the most potential are developed further and assessed again, with the identification of critical technologies needing further development. Independent studies by interested countries will be conducted over a period of 12-18 months with 2-3 joint meetings throughout to exchange data and findings. Details of the study are yet in the early planning stages.

The key elements of our future acquisition activities for the ATT in the near term include 2nd Iteration studies, Concept Direction studies, and Demonstration/Validation. We are currently in the early portion of our 2nd Iteration studies investigating both STOL and VSTOL concepts. Concept Direction studies will focus onto a single concept while Demonstration/Validation could pave the way for an advanced airlifter by approximately 2005 at the earliest. Concurrent with these activities are various ongoing working groups, individual study efforts, and technology initiatives throughout government and industry, all under the advanced airlift umbrella.

CLOSING REMARKS

As evidenced by the results reported in this paper, there is much US interest in an advanced theater airlifter. To date, we've defined the problem, established the key needs, identified the key tradeoffs, and have begun to analyze them. The STOL aircraft represents the low risk approach. The propeller VSTOL in a variety of forms looks promising in many respects, but much work yet remains. With the austere defense budgets predicted for the future, there is a great need for encouraging international cooperation. The cargo handling initiative may be the beginning of what could lead to an international aircraft development effort that could have broad implications for both military and commercial transports of the future.

- WITH PERCEIVED CHANGES IN
  - DOCTRINE
  - THREAT
  - MISSION

  NATURE OF WARFARE

- ARE TECHNOLOGY PLANS SUFFICIENT TO SUPPORT 21ST CENTURY SYSTEM DEVELOPMENTS FOR INTRATHEATER AIRLIFT?

- WHAT ARE THE KEY SYSTEM-LEVEL TRADEOFFS?

FIG 1
WHY AN ADVANCED THEATER TRANSPORT

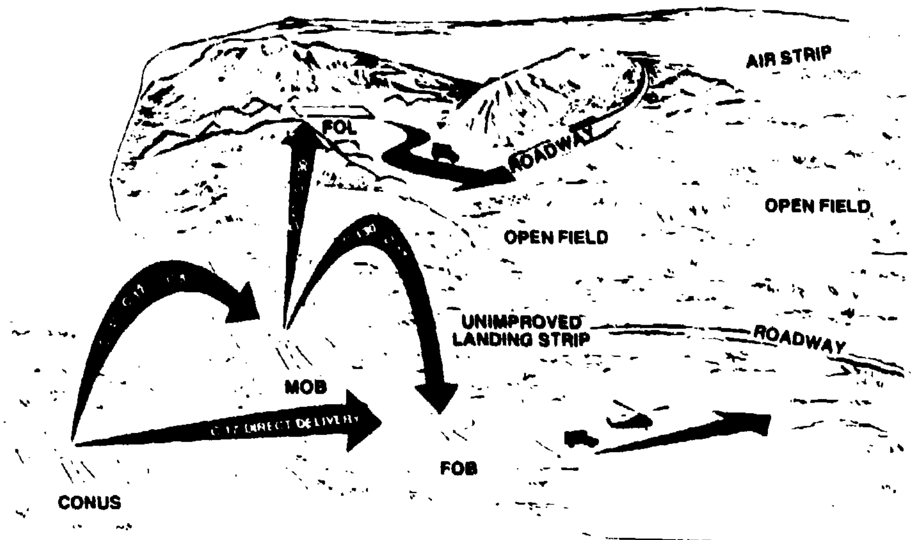


FIG 2
CURRENT AIRLIFT OPERATIONS

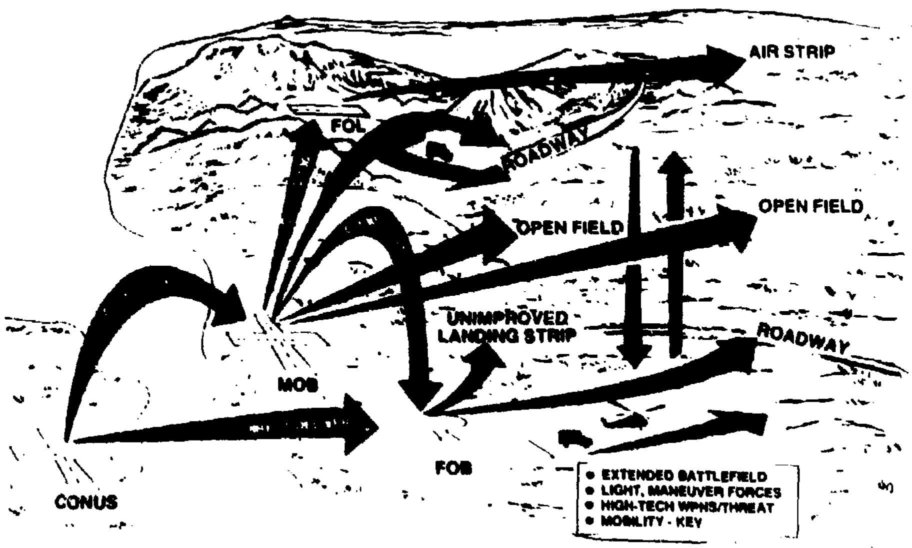


FIG 3
FUTURE AIRLIFT OPERATIONS

- NEEDS ANALYSIS
  - THREAT
  - INTRATHEATER JOBS
  - C-130/C-17 BASELINE
  - DEFICIENCY ANALYSIS
- TECHNOLOGY OPPORTUNITIES
- SYSTEM CONCEPTS
- EVALUATION

FIG 4
APPROACH

- BY THEATER
  - EUROPE - SOUTHWEST ASIA - CENTRAL AMERICA
- BY CATEGORIES
  - DEPLOYMENT
  - RETROGRADE
  - RECONSTITUTION
  - EMPLOYMENT
  - ALTERNATE MISSIONS
- BY SPECIFIC CHARACTERISTICS
  - SPECIFIC CARGO
  - FREQUENCY
  - THREAT
  - TONNAGE
  - ENTRY/DELIVERY
  - PRIORITY

FIG 5
JOB
DEFINITIONS

UNIT MOVE [36]
MLRS BN (2)
A-X SQDN (5)
HAWK BATTERY (4)
ATF SQDN (6)
AIRLIFT SQDN (1)
BDE MOVE (2)
MOBILE HOSPITAL (1)
AIR AMBULANCE CO (1)
POMCUS/UNIT MARRIAGE (5)
BN TASK FORCE (1)
DEEP ATTACK (1)

ROUTINE RESUPPLY [20]
USAF BASE (10)
AMMO/POL (6)
ADMINISTRATIVE (29)
RATIONS (8)
PERSONNEL REPLACEMENT (12)

EVACUATION [8]
BERLIN (8)
MEDICAL (20)
KIAS (30)
REFUGEES (6)

EMERGENCY RESUPPLY [31]
CRITICAL EQP'T (10)
CHEM GEAR (68)
AMMO (5)
BN (14)
PGM/POL (34)
SPEC WPNS (4)
UNIT RELOCATION (5)
EQUIPMENT MOVE (50)

RETROGRADE [5]
EQUIPMENT (28)
A-X SQDN (1)

[ ] % TOTAL WT AIRLIFTED
( ) JOB FREQUENCY

FIG 6
REPRESENTATIVE
JOBS-EUROPE

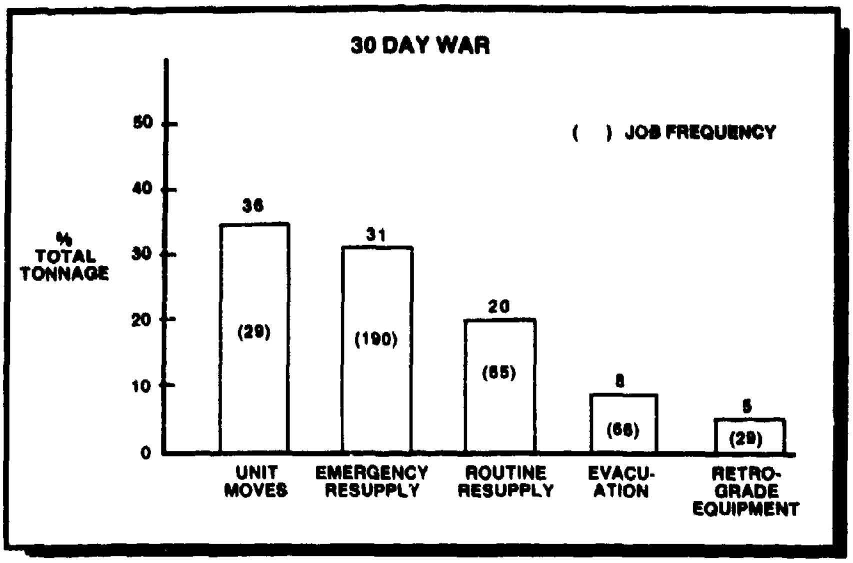
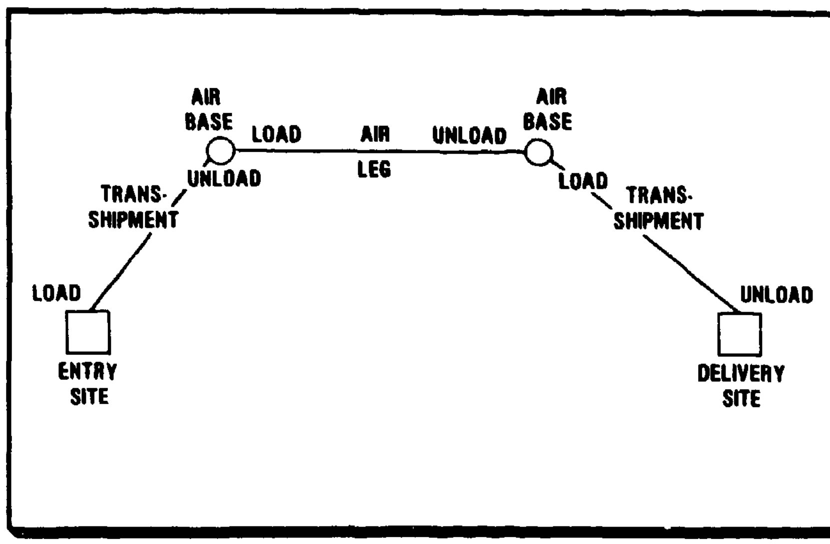
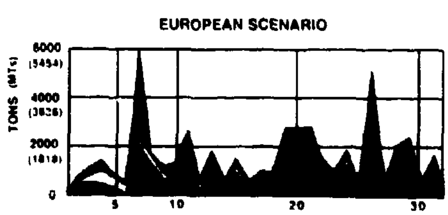


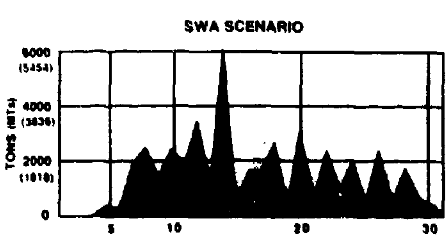
FIG 7
REPRESENTATIVE
TONNAGE
EUROPE

FIG 8
ENTRY-TO-
DELIVERY





TONNAGE DEMAND 30 DAYS			
	EUROPE	SWA	CA
TONS (MTs)	49706 (45187)	41181 (37437)	10438 (9489)
PAX %	23	18	22
BULK FUEL % AMMO	13 12 (44) 19	5 8 (31) 18	16 24 (48) 8
VEHICLES + OUTSIZE	33	51	30
ACROSS FLOT %	4.5	3.0	48
NEAR FLOT	5.0	5.5	11



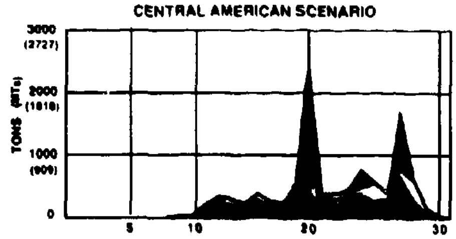


FIG 9
REPRESENTATIVE
DEMAND
FUNCTIONS

BOX SIZE

CONCEPT TYPE	SMALL	MEDIUM (C-130H SIZE)	LARGE	CONTRACTOR
STOL	USB TF EBF TF EBF PF	EBF TF EBF PF	EBF PF USB TF EBF TF EBF PF	BOEING DOUGLAS LOCKHEED
LO STOL	EBF TF	LIFT FAN + CRUISE	EBF TF	B D L
VSTOL	TILT WING TP	LIFT + CRUISE TILT PROP	LIFT + LIFT CRUISE	B D L
LO VSTOL	LIFT + CRUISE LIFT + LIFT CRUISE	LIFT + CRUISE	LIFT + CRUISE LIFT FAN + CRUISE LIFT + LIFT CRUISE	B D L

FIG 10
ATTMA
CONCEPT
MATRIX

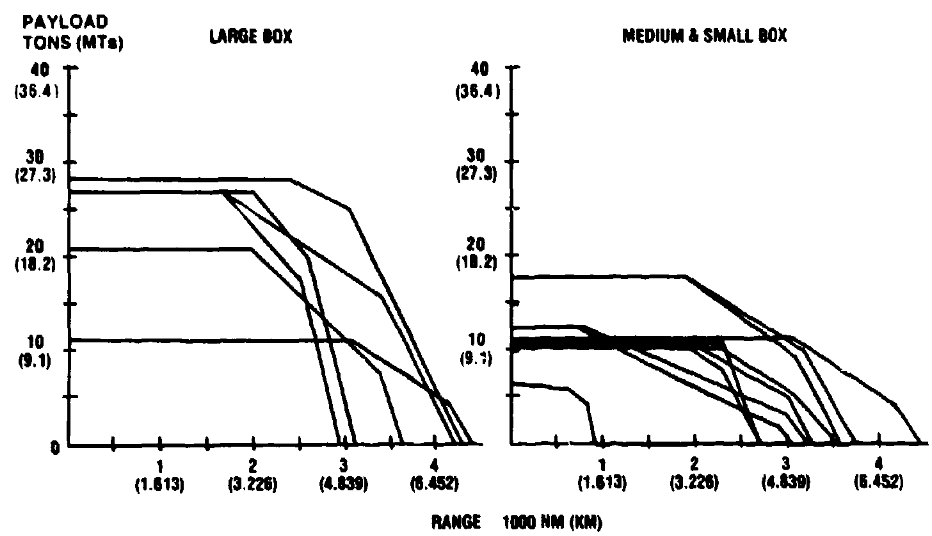


FIG 11
PAYLOAD
RANGE

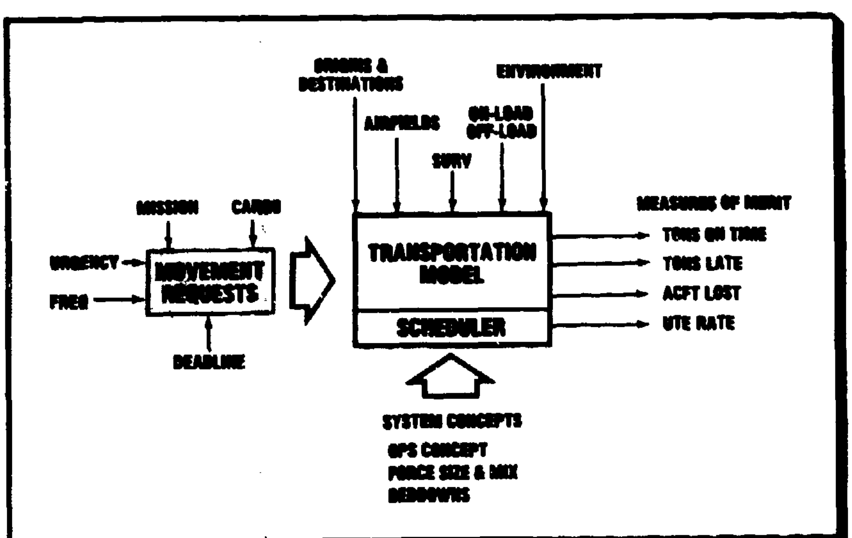


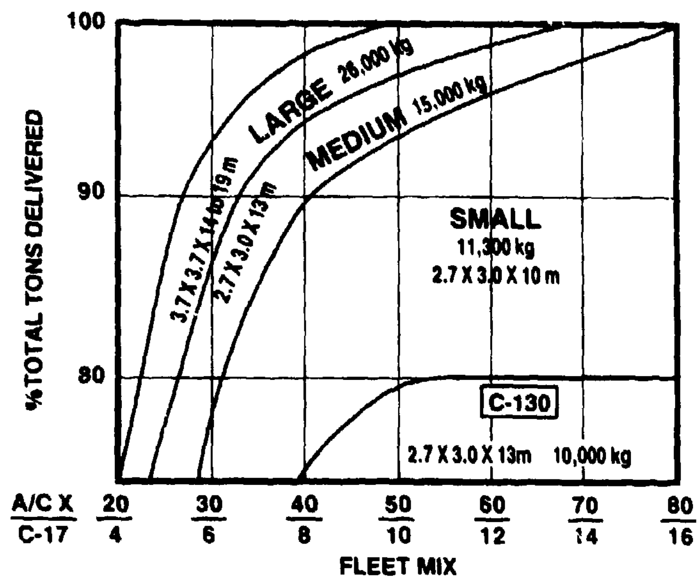
FIG 12
GENERALIZED
AIR MOBILITY
MODEL (GAMM)

EQUAL FLEET SIZE — 30 DAY WAR

CONFIGURATION	SIZE	EUROPE	SW ASIA	CA
BASELINE	MED	1.0	1.0	1.0
C STOL	LARGE	1.4	$\boxed{1.6}$	2.1
	MED	1.4	1.4	2.1
	SMALL	1.4	1.3	1.5
LO STOL	LARGE	1.3	1.4	1.8
	MED	1.3	1.4	2.0
	SMALL	1.3	1.2	1.4
C VSTOL	LARGE	1.2	$\boxed{1.6}$	2.0
	MED	1.3	1.5	$\boxed{2.3}$
	SMALL	1.2	1.3	1.4
LO VSTOL	LARGE	1.2	1.5	1.7
	MED	1.3	1.3	$\boxed{2.3}$
	SMALL	1.2	1.5	1.4

FIG 13 NORMALIZED FLEET EFFECTIVENESS

FIG 14 STOL PRODUCTIVITY EUROPE



- SHORT FIELD CAPABILITY
- MAX PAYLOAD-MULTI-LAUNCH ROCKET SYSTEM (MLRS)
- SOFT FIELD/TAKEOFF AND LANDING
- TERRAIN FOLLOWING/TERRAIN AVOIDANCE
- LANDING WITHOUT AIDS
- 3-MAN CREW
- SELF LOAD/UNLOAD
- STATION KEEPING
- IMPROVED AERIAL EXTRACTION
- NIGHT/ADVERSE WEATHER OPERATIONS

FIG 15 PERCEIVED NEEDS

- REAL-TIME MISSION PLANNING
- HIGH SURVIVABILITY-IN AIR/ON GROUND
- RELIABILITY/MAINTAINABILITY
- REPAIRABILITY
- COMPATIBILITY WITH OTHER AIRLIFTERS
- LOW SPOT FACTOR/GOOD GROUND MOBILITY
- CONVERTIBILITY TO MEDICAL EVACUATION
- HIGH UTILITY FOR ALTERNATE MISSIONS
- AFFORDABILITY
- AERIAL REFUELING

FIG 16
PERCEIVED
NEEDS (CONT)

- INFRASTRUCTURE DEPENDENT
  - LONG, HARD-SURFACE LANDING SITES
  - NUMBER & DENSITY OF LANDING SITES
  - ROADS, TERRAIN, ETC
- TIED TO 463L SYSTEM
  - RESOURCE LIMITED
  - AGING
  - LONG DELAYS
- AIRDROP
  - INEFFICIENT
  - HEAVY TRAINING BURDEN
- NOT SURVIVABLE
- LIMITED C^3I
- HIGH OPERATING & SUPPORT COSTS

FIG 17
AIRLIFTER
PRODUCTIVITY
TODAY

- TODAY'S DEFICIENCIES MAY BE GREATLY REDUCED WITH
  - SHORT FIELD CAPABILITY
  - SOFT SURFACE LANDING GEAR
  - SELF LOAD/UNLOAD
  - SURVIVABILITY-ON GROUND & IN AIR
  - C^3I TIE WITH USER AND MISSION PLANNING
- FUTURE THRUST
  - JOINT ACTIVITIES (HQ MAC & ARMY)
  - CONTINUED TECHNOLOGY DEVELOPMENT
  - CONCEPT DEVELOPMENT
  - CONCEPT OF OPS DEVELOPMENT
  - IMPROVEMENT OF TOOLS (MODELS)
  - INTERNATIONAL COOPERATION

FIG 18
AIRLIFTER
PRODUCTIVITY
TOMORROW

- DETERMINE MISSION NEEDS
  - CARGO
  - ENVIRONMENT
  - MODE INTERFACES
  - LOAD/UNLOAD TIMES
  - THREAT
  - REPRESENTATIVE MISSIONS
- EXPLORE BROAD RANGE OF SOLUTION CONCEPTS
  - NOTIONAL/INNOVATIVE
  - SCREENING METH'Y
  - IDENTIFY HIGH PAYOFF CONCEPTS
  - TECHNOLOGY AUDIT TRAIL
- DEVELOP/EVALUATE HIGH PAYOFF CONCEPTS
  - FIRST ORDER DESIGNS TO ASSESS FEASIBILITY
  - METHODOLOGY AND COMPARISON OF ALTERNATIVES
  - IDENTIFY CRITICAL TECHNOLOGIES
- RECOMMEND FUTURE FOLLOW-ON ACTIVITY

FIG 19
CARGO HANDLING
STUDY

DESIGN OF THE ADVANCED CARGO AIRCRAFT THE U.S. ARMY'S NEXT GENERATION TRANSPORT ROTORCRAFT AN OVERVIEW

by

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AD-P006 242

Summary

A family of rotorcraft were defined to meet the projected requirements of the U.S. Army for combat airlift in the year 2000 and beyond. A detailed definition of equipment and mission load inventories was developed, and a knowledge-based simulation assessed the capability of various-size aircraft to transport these inventories in three combat theaters: Europe, Southwest Asia, and Latin America. Payload capabilities of 18, 26, 30, and 39 thousand lb (8,165, 11,793, 13,608, 17,690 kg) with 270 nm (500 km) radius of action at Army hot day ambients were identified as potentially cost effective design points. A 9 X 9 ft (2.74 X 2.74 m) cabin cross section was required, with a cabin length of 32 to 41 ft (9.75 to 12.5 m) depending on design payload. Single and tandem rotor helicopter solutions were defined for each of the four design payloads. A tilt rotor solution was also examined. A single rotor configuration with a design gross weight of 94,000 lb (42,637 kg), a rotor diameter of 122 ft (37.2 m), and three engines served as a baseline for evaluation of the impact of various design criteria and system technology levels.

(25) * Helicopters, * Jet transport aircraft, * Airlift equ...

Analysis

The U. S. Army has identified a need to replace their existing medium lift cargo helicopters (CH-47s) with an Advanced Cargo Aircraft (ACA) that will enhance present combat airlift capabilities with increased payload capacity, increased range and survivability, and greater mission versatility, flexibility, and responsiveness. This new aircraft, presently scheduled for initial operational capability (IOC) in 2015, will support the goals of the Army of Excellence and will constitute an essential element of the Airland Battle Doctrine for the coming century. It will be required to transport a wide variety of loads under the stressful conditions of combat worldwide. The cornerstone of the ACA design must be its flexibility, versatility, and ease of handling a diversity of combat multipliers. It must be designed to provide the Army's tactical link to the Air Force's strategic lift capabilities, and to facilitate the timely transfer of necessary stores and supplies from the supply points down to the combat user levels. An effective ACA will be one that provides the local Commander freedom to determine what critical supplies are moved and where, based upon his on-the-spot assessment of user needs and the criticality of his missions. The ACA must be an effective combat multiplier itself, enabling the Commander to rapidly shift his assets in a way that brings about a positive and decisive outcome to the battle.

The Aviation Applied Technology Directorate (AATD) of the U. S. Army at Ft. Eustis, Virginia, contracted with Sikorsky Aircraft to conduct a study of ACA design requirements. The approach taken to define the best ACA design comprised three separate tasks: definition of airlift requirements, evaluation of a family of aircraft designs in simulated combat operations, and identification of needed technology exploitation.

In the first task, an assessment was made of the combat and combat service support airlift movement needs. This task included projection of the current vehicle and equipment inventory into the future operational time frame, definition of scenarios for several potential conflict intensity levels, and prediction of the relative frequency of movement needs. A listing of load items anticipated for rotorcraft transport in a year 2015 time frame was compiled from the inputs of 19 different U. S. Army organizations. Each load item was characterized by its weight, dimensions, whether it can be carried externally, whether it is stackable internally, and what its typical aircraft load and unload times are. Load items ranged from a 240-lb (109-kg) trooper to a 110,800-lb (50,258-kg) M-88 recovery vehicle.

Drawing from the compiled equipment list, eight general categories of missions were developed to represent future U.S. Army combat airlift requirements. Figure 1 provides examples of the selected missions, which ranged from combat resupply to the movement of outsized equipment. These missions were incorporated into three representative theaters of operation; Europe, Southwest Asia, and Latin America, to create a total of 24 unique missions. These theaters were selected based on the likelihood of future U.S. Army involvement, and provide a wide range of ambient conditions (Europe 2000 ft, 70°F (610 m, 21°C), Latin America 3000 ft, 85°F (914 m, 29°C), Southwest Asia 4000 ft, 95°F (1219 m, 35°C)). Detailed mission descriptions were then developed listing the load items, mission profiles, expected level of threat, and realistic operational constraints. The load item list for each mission included weight and dimensions as well as item quantity and a numerical ranking of item priority. Load item priority was ranked from 1 (lowest) to 9 (highest) based on the item's ability to impact the outcome of the battle or event. Mission flight profiles described mission leg lengths and headings and included features such as assembly areas, pickup points, air control points, drop-off points, and refuel support areas. Mission geometries were derived from actual geographical maps and included the impact of topographic features, existing airfields, harbors, and transportation infrastructure.

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The second task drew upon the results of Task I to create an expert system simulation model which helped determine cabin dimensions and payload capability which maximized vehicle productivity. The assessment of the performance of a large collection of aircraft sizes in the 24 missions required a new analysis tool to manage the large number of variables and combinations involved. A knowledge-based simulation was developed by software engineers at the United Technologies Research Center to model the rotorcraft cargo transportation task. Key elements of the transport task include the packing of the aircraft (how to most efficiently load individual items in a specified cabin size), flight routing, and fuel management. Rules were developed by logistics experts for each of these elements and were combined with the details of the 24 missions to create a realistic operational simulation. Features included the trading of fuel for additional payload if mission legs permitted, and an accounting of time and fuel spent in loiter awaiting availability of finite area landing zones. Detailed results are provided on an individual and aggregated mission basis, and include over 30 mission performance parameters describing the utilization, effectiveness, and efficiency of each vehicle size.

Three measures of effectiveness (MOE's) were selected to identify optimum sized aircraft. Ton-miles is a traditional MOE often used in cargo transport analysis. Simply the product of tons of cargo and number of miles traveled, this measure reveals nothing about the efficiency of the aircraft size in relation to the cargo items carried. The larger the aircraft the better. Specific productivity is another widely used MOE that normalizes ton-miles by dividing it by mission time and aircraft weight empty. Mission time reflects delivery speed, and weight empty is analogous to vehicle cost. Specific productivity therefore represents relative efficiency in delivering cargo.

While measuring efficiency, however, specific productivity provides no indication of the vehicle's effectiveness in carrying every load within a given mission. For example, analysis of the simulation output indicated that a relatively small ACA, although very efficient, carried only 75% of the cargo items listed for a mission due to its limited lift capability. A less efficient but larger ACA had a lower specific productivity, but delivered over 95% of the mission cargo. A new MOE termed priority effectiveness was developed and used along with specific productivity to identify both efficient and effective aircraft sizes. Priority effectiveness is the fraction of cargo items delivered weighted by their relative priority. It is the ratio of actually delivered priority value to that mission's available priority value. Thus, priority effectiveness penalizes a design that leaves uncarried loads behind and rewards a design that delivers a large percentage of high priority loads.

As a final measure, priority effectiveness is combined with specific productivity to provide an overall MOE, priority productivity, that captures the impact of both an efficiently sized aircraft and a mission effective aircraft. Figure 2 compares the results obtained using specific productivity with the corresponding priority productivity results. In this example an ACA with a 36,000-lb (16,329-kg) payload has a greater MOE value than one with an 18,000-lb (8,165-kg) payload because of its increased effectiveness in the mission. A new point of interest is also exposed at 30,000-lb (13,608-kg), as this size aircraft benefits from a jump in effectiveness but not in efficiency. In general, the effectiveness fraction tends to bias the selection towards the larger, more effective sizes. This bias decreases as payload capacity increases until either a priority effectiveness fraction of 1.0 or the maximum value of effectiveness possible for a particular cabin size is obtained. Table 1 provides a summary of the selected measures of effectiveness.

TABLE 1. SUMMARY OF MEASURES OF EFFECTIVENESS

MOE	Definition
Specific Productivity	$\dfrac{\text{cargo weight X miles carried}}{\text{mission time X empty weight}}$
Priority Effectiveness	$\dfrac{\text{priority value delivered}}{\text{priority value possible}}$
(where priority value = priority value X load item quantity)	
Priority Productivity	specific productivity X priority effectiveness

One hundred and sixty combinations of payload capacity and cabin dimensions were evaluated in an initial optimization process using the knowledge-based simulation. Four locally optimum payload capacities were identified, and an optimum cabin cross section was selected. Simulation data were aggregated using the anticipated frequency of operation for each mission within a theater to create weighted average theater-level results. All-theater results were then derived using a weighted average of the three theater-level results.

Cabin lengths from 24 to 52 ft (7.3 to 15.8 m) and payload capacities from 14,000 to 40,000 lb (6,350 to 18,144 kg) were addressed in the initial run matrix. The 4000 ft, 95°F (1219 m, 35°C), 270 nm (500 km) radius of action payload capacities are used only as a common reference; the payload capacities are greater at less demanding ambient conditions and mission distances. A coupling between payload capacity and cabin length was clearly seen at about a 26,000-lb (11,793-kg) payload capacity. Beyond this, increasing payload capacity required an increased minimum cabin length to benefit from increased lift capability. Table 2 provides a listing of these payload capacity selections and their corresponding cabin lengths.

TABLE 2. FIRST ITERATION SIZE SELECTIONS

Payload capacity (4000 ft, 95°F) (lb)	(kg)	Cabin Length (ft)	(m)
18,000	8,165	32	9.75
24,000	10,886	36	10.97
30,000	13,608	36	10.97
38,000	17,236	40	12.19

For each of the initially selected aircraft sizes in Table 2, cabin width and height were varied to identify any coupling relationships and to make preliminary selections. Using priority productivity, each size exhibited optimum capability at a cabin height of 102 in. (259 cm). The loads driving the cabin height selection were identified by the simulation to be a collection of wheeled vehicles including the HEMTT.

Similar data were compiled for cabin width. As was the case for height, each aircraft size was found to have the same optimum cabin width, 96 in. (244 cm). The cargo items driving the width selection were identified to be particular containers and pallets including the palletized loading system (PLS) flatrack and 20-ft (6.1-m) containers.

A cabin cross section was developed incorporating the selected dimensions. A military standard 6-in. (15-cm) clearance was provided above the load and between the side of the load and the cabin walls, making the resulting internal dimension 9.0 ft by 9.0 ft (2.74 m by 2.74 m). This cross section was used in all subsequent simulations and design studies.

A second series of simulations was conducted to complete the design optimization, with more rigorous analysis of locally optimum payload capacities and the corresponding optimum cabin lengths. Data were again collected on a mission level and aggregated to theater-level results.

The European missions generally feature medium-length mission legs and a large spectrum of cargo item sizes, with many items under 5,000 lb (2,268 kg) and many over 30,000 lb (13,608 kg). Trades of fuel for additional payload can be in excess of 10,000 lb (4,536 kg). Vehicle specific productivity is typically driven by combinations of cargo loads of several items and not by individual items. Aircraft payload capacity at the European ambients of 2000 ft, 70°F (610 m, 21°C) and the medium ranges is of the order of 150% of the reference 4000 ft, 95°F (1219 m, 35°C), 270 nm (500 km) radius of action payload capacity. Given the large payload capacity, typical aircraft sizes are volume-limited well before becoming lift-limited. Major peaks of performance were identified at 25,000-, 39,000-, and 50,000-lb (11,340-, 17,690-, and 22,680-kg) (4000 ft, 95°F) payload capacities with a minor local peak at 18,000 lb (8,165 kg).

The Southwest Asia missions feature very long mission legs with up to 270 nm (500 km) radii of action. These missions were also flown at the most stringent ambients, 4000 ft, 95°F (1219 m, 35°C). Rotorcraft airlift is seen as playing a major role in this theater due to the lack of a reliable transportation infrastructure, the result being large numbers of items of various types in the mission lists. Missions often require nine or more sorties of an eight-aircraft company to deliver all cargo. Aircraft sizes that can carry a greater number of items per load reduce the number of sorties required. The combination of long mission legs and high density altitude yield low payload capacities, and aircraft are frequently lift-limited before becoming volume-limited. The mission ranges required also discourage the use of external lift. Specific productivity peaks and levels off at 44,000 lb (19,958 kg) design payload, after which increasing aircraft weight empty reduces the specific productivity.

Latin America missions are typically short to medium in length and are flown at an intermediate ambient condition. The large variety of load items seen in the other theaters is reduced, such that individual cargo items can have a substantial impact. External lifts are frequently used and internal fuel is often reduced as much as 50% of fuel capacity, or 7,000 to 8,000 lb (3,175 to 3,629 kg). Local peaks in specific productivity occurred at 17,000-, 30,000-, 37,000-, and 46,000-lb (7,711-, 13,608-, 16,783-, and 20,865-kg) design payload. Each optimized payload requirement is the result of a specific additional capability that occurs at that point. At 17,000 lb (7,711 kg) a MILVAN becomes a viable load, at 30,000 lb (13,608 kg) the 20-ft (6.1-m) containers are transportable, at 37,000 lb (16,783 kg) efficiency jumps as certain double payloads become possible, and at 46,000 lb (20,865 kg) the long 48-ft (14.6-m) cabin increases internal lift capacity.

Each theater was assigned a weighting factor incorporating probability of utilization and intensity of conflict. Initial weighting set usage at 50% Europe, 25% Southwest Asia, and 25% Latin America. Using these theater weighting factors, individual theater results were combined into the all-theaters result shown in Figure 3. With these results the final payload capacity selections were made. Peaks identify locally optimum payload capacities at 18,000, 26,000, 30,000, and 39,000 lb (8,165, 11,793, 13,608, and 17,690 kg) at the 4000 ft, 95°F (1219 m, 35°C) ambient condition. Payload capacities beyond 42,000 lb (19,051 kg) were not considered due to the unrealistic aircraft sizes that result. Optimum cabin lengths were selected by varying cabin length for each selected payload capacity. A 32-ft (9.75-m) cabin length was selected for the 18,000-lb (8,165-kg) payload capacity aircraft. Both the 26,000-lb (11,793-kg) and 30,000-lb (13,608-kg) solutions require a 35-ft (10.67-m) cabin, and a 41-ft (12.5-m) cabin was matched to the 39,000-lb (17,690-kg) size.

Once optimum cabin size and payload lift capability were determined by the simulation, several "families of designs" were created to address conceptual design considerations. Table 3 summarizes the selected payload capacities and cabin dimensions for the family of ACA designs. Also listed is priority effectiveness for each of the selected sizes. This value represents the weighted average across all missions and all theaters. The payload capacity dictates the installed power and dynamics system sizing and the cabin dimensions define the fuselage geometry. These data were used to establish more detailed design solutions at each aircraft size for the purpose of down-selecting to a recommended ACA size.

Detailed designs were created for single, tandem, and tilt rotor solutions. Several design criteria were prescribed to ensure a level of commonality between the four selected design points. A design mission with a 270 nm (500 km) radius of action at 4000 ft, 95°F (1219 m, 35°C) was used. Figure 4 shows the design mission profile. Aircraft equipment requirements were provided by the Army or were established in communications with military personnel familiar with cargo aircraft operations. Key ACA operational and systems requirements include health monitoring and two-level maintenance capability, all-weather-day/night operations, extensive survivability and self-defense suites, and advanced load handling equipment.

TABLE 3. ACA SELECTED SIZES - SECOND ITERATION

Payload at 4000 ft, 95°F (lb/kg)	Cabin Length (ft/m)	Cabin Width (ft/m)	Cabin Height (ft/m)	Priority Based Mission Effectiveness
18,000 (8,165)	32 (9.75)	9 (2.74)	9 (2.74)	76%
26,000 (11,793)	35 (10.67)	9 (2.74)	9 (2.74)	84%
30,000 (13,608)	35 (10.67)	9 (2.74)	9 (2.74)	89%
39,000 (17,236)	41 (12.50)	9 (2.74)	9 (2.74)	93%

A maximum main rotor disk loading of 10 psf (478.8 nt/sq m) was mandated to permit unrestricted operations by ground personnel in the rotor downwash. A 1.75g normal load factor capability at 150 kts (278 kph) was provided. The fuselage and landing gear were designed to stringent UH-60 levels of crashworthiness.

Aerodynamic and weights technology levels were representative of 1990 state-of-the-art design. Extensive use was made of composite structure in both the fuselage and dynamic system. Drive system technology levels were derived from design efforts in a NASA-sponsored Advanced Rotorcraft Technology (ART) transmission program. A survey of current and future engine technology programs resulted in the selection of 6000 shp (4474 kw) class turboshaft engines.

Figure 5 shows the profile view of the ACA single rotor family of designs. The Lockheed C-130 transport and the CH-53E are shown for scale. Single rotor design solutions have gross weights ranging from 75,500 lb (34,246 kg) for the 18,000-lb (8,165-kg) payload size, to 126,600 lb (57,424 kg) for the 39,000-lb (17,690-kg) payload size. The two smaller designs use three 6000 shp (4474 kw) class engines while the larger designs use four. The 18,000- and 30,000-lb (8,156- and 13,608-kg) payload aircraft have disk loadings of 10 psf (478.8 nt/sq m), whereas the other designs required a reduction in disk loading to match hover power required with power installed. All designs employ a canted tail rotor which provides from 2,000 to 3,000 lb (907 to 1,361 kg) of vertical lift.

Tandem rotor design solutions were developed using identical design criteria as for the single rotor designs to the extent possible. Configuration commonality was maintained between families of designs by using the same cockpit, cabin section (where possible), and systems. All tandem rotor designs utilized four-bladed rotors, a 30% rotor overlap-to-diameter ratio, and a 0.15 gap-to-stagger ratio. Figure 6 depicts the resultant family of tandem rotor helicopter designs. The result of greatest interest when comparing single and tandem rotor designs was the similarity in gross weights at each design point. The tandem rotor designs typically have slightly lower weight empty which is balanced by increased fuel requirements. Simulation-selected sizes based on single rotor trending should therefore be generally applicable to tandem rotor designs as well. As in the single rotor designs, the two larger tandems use four engines and the 26,000- and 39,000-lb (11,793- and 17,690-kg) payload sizes require reduced disk loadings to match powers.

A tilt rotor design provided gains in mission productivity where internal loading and long mission legs permitted it to take advantage of higher speed capability, but its significantly higher weight, installed power, and disk loading make it an unattractive ACA solution.

Takeoff gross weight capability for the mission simulation was based on hover out of ground effect at 95% intermediate rated power (IRP) with a 200 fpm (1.0 mps) vertical rate of climb at the appropriate ambient conditions. The mission performance benefits of using takeoff techniques other than a standard hover were assessed by calculating payload capabilities for a variety of takeoff procedures. Techniques included rolling takeoffs, a hover takeoff using a higher short-term engine rating, and twin lift using two aircraft to lift a single very heavy external load. Individual takeoff techniques were matched to particular missions based on their suitability. For example, rolling takeoffs were used only with internal loads and where a runway was available, and twin lift was not used in high threat environments.

Figure 7 shows the impact of the use of alternate lift techniques on the overall priority effectiveness of the four sizes of aircraft. Using alternate lift the 39,000-lb (17,690-kg) payload size becomes 100% effective, being able to lift every item in every mission load list, including the the 110,800-lb (50,258-kg) M-88 recovery vehicle, which is twin-lifted in Europe. The 30,000-lb (13,608-kg) payload aircraft becomes over 99% effective, leaving only four loads behind. The greatest gains in effectiveness are realized at the 26,000-lb (11,793-kg) size, where effectiveness jumps from 84% to 98.5%. The smallest size shows substantial gains as well. The use of an aircraft size which is well matched for all but a few loads but can then transport those loads using special mission tactics, is seen as a substantial cost saving opportunity.

Selection of a recommended solution from the family of ACA designs involved evaluation of technical risk, procurement and life-cycle costs, and mission effectiveness. Given the high mission effectiveness achievable with the 26,000-lb (11,793-kg) payload aircraft using suitable alternate lift techniques, it was concluded that this aircraft provided the most attractive solution.

The study resulted in the following conclusions:

1. Eighty-five percent of the individual loads requiring airlift in support of U.S. Army intra-theater combat weigh less than 50,000 lb (22,680 kg). When frequency of need is considered, 90% of required mission loads weigh less than 30,000 lb (13,608 kg). The loaded PLS flatrack, in the 30,000-lb weight class, is a key driver of aircraft payload and cabin volume requirements.

2. A cost-effective aircraft size corresponds to the capability to take off vertically with 26,000 lb (11,793 kg) of payload, plus fuel for 270 nm (500 km) radius of action, at 4000 ft, 95° F (1219 m, 35°C). At sea level standard day and short ranges, lift capability is in excess of 50,000 lb (22,680 kg).

3. When rolling takeoff, use of a higher engine rating for takeoff, or twin lift (two aircraft acting together to lift a single load) is operationally viable, the already small number of non-liftable mission loads is reduced significantly.

4. The aircraft cabin should have an internal cross section of at least 9 x 9 ft (2.74 x 2.74 m), and an unobstructed length of at least 35 ft (10.67 m).

5. A helicopter meeting the above requirements with 1990 advanced level technology would have a design gross weight on the order of 94,000 lb (42,637 kg), and require three engines in the 6,000 hp (4,474 kw) class.

6. Single rotor and tandem rotor helicopter solutions provide about the same mission productivity for about the same weight and cost. Other attributes would have to be considered to discriminate between them.

7. The modest improvement in overall productivity that is potentially achievable with a tilt rotor would not appear to justify the higher weight, greater installed power, and harsher downwash environment.

8. A three-engine helicopter solution provides the most efficient match of total and engine-out power requirements. A larger engine should be considered for aircraft sizes requiring more than three 6000 shp (4474 kw) class engines.

9. Technology beyond what is currently in production is needed to produce an ACA with reasonable weight and cost. Without this technology, aircraft weight would increase on the order of 17%, or 16,000 lb (7,257 kg). The key areas where technology advances need to be concentrated are composites, transmissions, rotors, and engines.

10. Judicious application of technology that is advanced beyond the levels assumed, and selective tailoring of design criteria, should make it possible to reduce the weight of the aircraft by approximately 8,000 lb (3,629 kg). The key technology is advanced composites for the airframe and rotors. The key design criteria is the engine power rating assumed to be available for takeoff.

CATEGORY	EXAMPLE	SAMPLE CARGO LOAD
COMBAT RESUPPLY Class V + Equipment	SHIFT COMBAT POWER AMMO & ARTILLERY	PALLETS W / AMMO
CLASS III MOVEMENT Aviation Fuel	FARP RELOCATION	BLADDERS & PALLETS
PERSONNEL	INFANTRY COMPANY RELOCATION	100 TROOPS W / WEAPONS
VEHICLE MOVEMENT	AIR DEFENSE SYSTEM RELOCATION	LIGHT VEH. W / CREW
RECOVERY OF EQUIPMENT	RECOVER DAMAGED AH-64 HELICOPTER	EQUIPMENT & CREW
DEEP BATTLE	RESUPPLY ISOLATED COMBAT FORCE	PALLETS & TROOPS
MEDICAL MISSIONS	RELOCATE MASH UNIT	PLS, SHELTERS & CONTAINERS
OUTSIZED EQUIPMENT	GAP or OBSTACLE CROSSING	ENGINEER EQUIPMENT

Figure 1. Eight catagories of U. S. Army cargo missions.

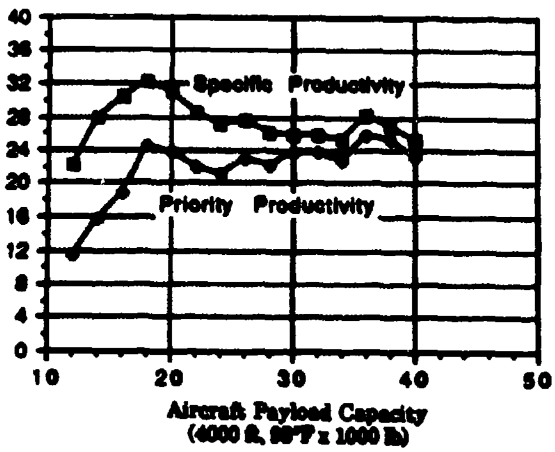

Figure 2. Impact of mission effectiveness on specific productivity.

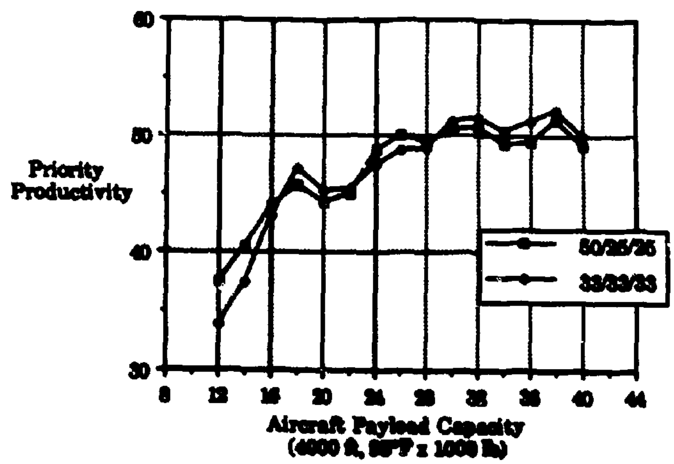

Figure 3. Impact of theater weighting factors on priority productivity.

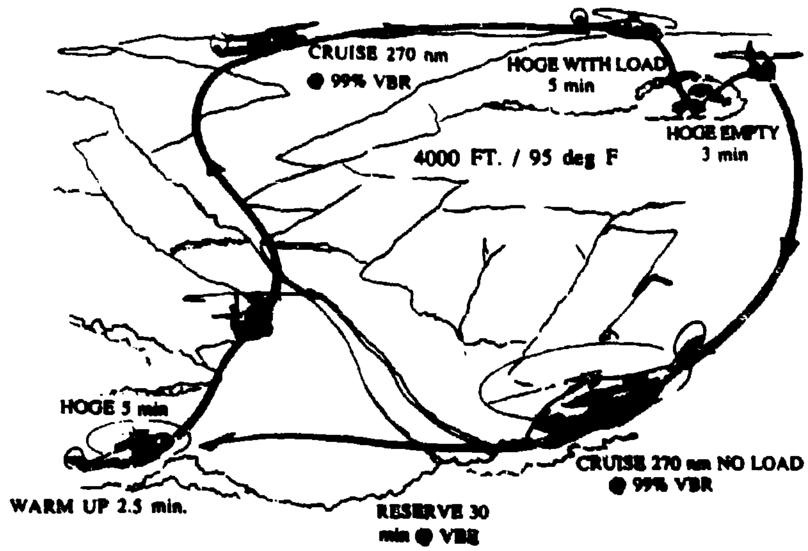

Figure 4. ACA design mission.

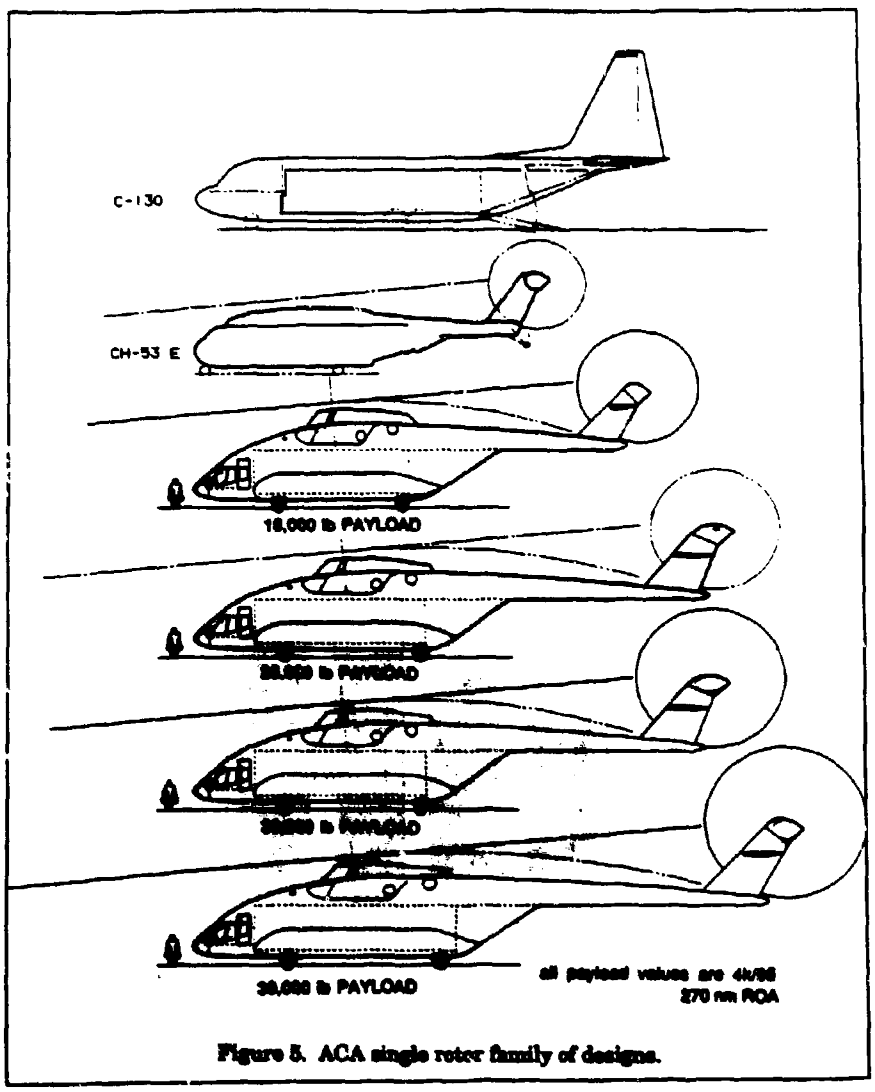

Figure 5. ACA single rotor family of designs.

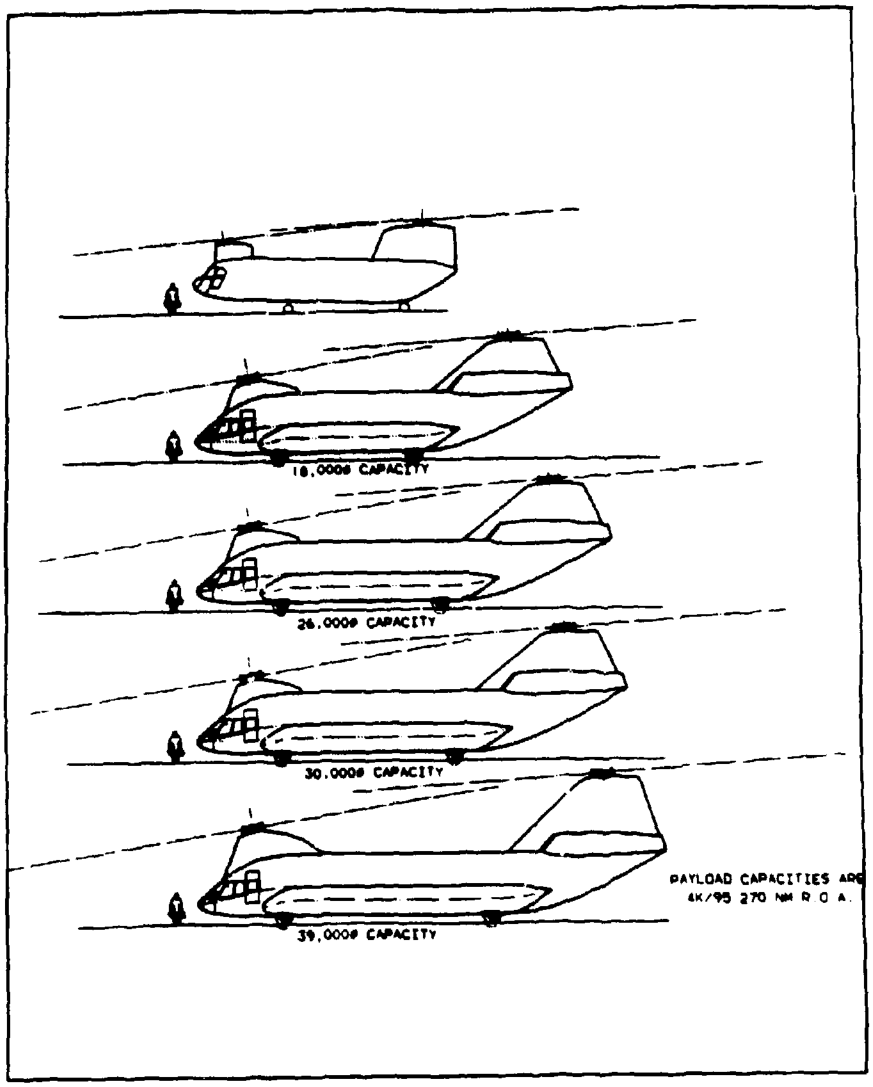

Figure 6. ACA tandem rotor family of designs.

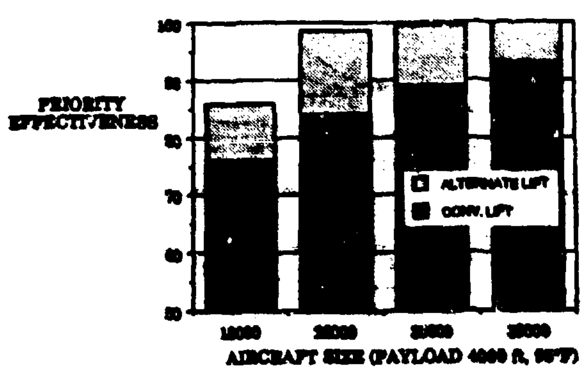

Figure 7. Impact of alternate lift techniques on effectiveness.

GENERAL CONFIGURATION ASPECTS ON AIRLIFTER DESIGN

by

AD-P006 243

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INTRODUCTION

This paper tries to briefly summarise the main constrains which must be covered during the prefeasibility phase in the airlifter design, based on the actual background of the Advanced Design Department of CASA.

Looking at the recent aviation history we can see that in the period before the II W W there was not any aircraft that could be considered to be designed under military transport criteria, certainly caused by the absence of the need of an airlifter system in the Airforces at that time, and the clear domain of the civil airlines requirements.

The II W W brought the necessity of real military transport aircraft that could be able not only to carry troops and paratroops but also loads and vehicles close to the first line of combat. This necessity developed in three directions:

1.- Specific transport gliders like the Airspeed Horsa, General Aircraft Hamilcar, Gotha 242, WACO CG - 13, etc.

2.- Conversion of civil airlines or even bombers into transports: Douglas DC-3 (C-47/53), Curtis C-47, Lockheed C-69, SM-75, JU-52, Avro York, etc. and

3.- Specific designs for military transport aircrafts: ARADO 232, Me 323, C-119 Packet, etc.

From this period some ideas came that are still in use today like the forward or rearward ramp door to easy the load and unload of the aircraft (Me 323, General Aircraft Hamilcar) or the multiple wheeled landing gear (Arado 232). (25) * Military [illegible], * Airlift operations, * Transport [illegible]

It was really in the 50's, and led by the experience of the Korean coflict, when the airlift groups of the Airforces become as important as they are today,that the design for specific military transport aircraft started everywhere, in an endeavor to meet typical requirements for this type of aircrafts: Short field length capability, easy onload and offload, load dropping capability, unpaved and unprepared runways, capability, good load capacity (in weight and volume),low maintenance, etc (C-130 Hercules, C-160 Transall, etc.).

Nowadays, a "new" factor has arisen with enormous importance, the costs. Itself it is not really new. The aircraft designers of the foregoing decades have had in their minds some kind of cost analysis. The really new item is the methodology and the computer tools that can allow us today to follow an exhaustive cost analysis and to compare a great number of possible configuration solutions to satisface the requirements.

Construcciones Aeronáuticas S.A. (CASA) was founded in 1923. The first design effort on transport aircraft came from the fourties when the design of the C-201 and C-202 and led into the development and production of the C-207 "AZOR" which was in service with the Spanish Air Force in the sixties.

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A very important milestone for the CASA design office was the design of the well known C-212 Aviocar in the sixties. Nowadays several versions of this aircraft have been developed including Maritime Patrol and Electronic Warfare. They are still in production and in service with a lot of Airforces all over the world. (More than 400 aircrafts sold).

In the 70's and 80's decades CASA designed the C-401 and CN-235 respectively. The last one, nowadays in production, represents the new generation of Medium Military Transport Aircraft.

CASA is one of the partners in the European Consortiums for the design and developement of the EUROFLAG and EUROFAR Programs on military transport.

2. REQUIREMENTS ANALYSIS

The analysis, from the Design Office, of the Requirements for the design and development of the configuration must be the first step before starting the design process.

This assessment must be driven to obtain a clear understanding of the real needs to be covered by the new design.

This target implies several technical studies to evaluate the implications on the configuration and also, identify the "cost driver" parameters to allow the designers to concentrate their effort on the optimization of those parameters.

In particular, this process becomes critical when it is involved in international programs which must take into account the requirements from various National Air Forces with several specific constrains.

This implies a large margin on each requirement and a different priority level on it. In this case, an harmonisation process must be carried out in order to obtain a final set of requirements to be assumed by each Nation involved in the program.

However, to get final agreement, the Design Offices must perform several trade-off studies in order to quantify the advantages and penalties to be paid by emphasizing one or another design parameter.

These studies are usually called Pre-feasibility Studies and they help the authorities to understand the implications on the aircraft of modifying the preliminary requirements. The Preliminary Requirements are officially endorsed in the European Staff Target (EST) which establishes the basic requirements to define the Baseline Configuration.

Following this process, the Feasibility Studies must be performed by the Project Offices to evaluate, in more depth, the real possibilities to full-fill the complete set of requirements and evaluate the penalties in weight, performance and cost.

These studies will help to determinate of the final requiremet to be imposed to the aircraft and including in the European Staff Requirement (ESR), as the bases from which to start the Project Definition Phase.

The requirement analysis process are sumarized on figure 1.

3. REQUIREMENTS VERSUS ALTERNATIVE CONFIGURATIONS

During the requirements analysis process several alternative configurations must be designed and evaluated by the Project Offices, prior to concentrating all their effort on the most promising ones.

At the end of the analysis, two or three alternative configurations may cover the requirements. To select the optimum one implies a methodology which will be presented later on this paper.

To ilustrate these items, some real examples will be presented.

CASA C-212

In 1964, CASA Projects Office started the first studies to design a new aircraft based on Spanish Air Force Specifications.

In summary, the main requirements were to design a multi-purpose transport aircraft able to replace the old JU-52 with capacity for small military vehicles and able to operate from unprepared short fields.

The main specifications to be full-filled by the C-212, are summarized in figure 2.

During a period of time of four years several configurations were evaluated, being finally selected two alternative configurations.

The main common characteristics of both configurations were : aircraft with high wing, monoplane and double-slotted flaps, unpressurized fuselage of "almost square" cross section and large access rear door, two turboprops, fixed tricycle landing gear and windscreen offering good visibility.

The first design was an aircraft configuration with straight wing and struts to support it. A three view drawing is shown in figure 3.

The finally selection was a configuration with a cantilever wing and a medium-high thickeness profile.

The optimum configuration is shown in figure 4 and in figure 5 is presented the actual configuration of the CASA C-212/S-300.

It is important to mention the operative weights evolution on this aircraft. The MTOW of the prototype was 6000 Kg and the present specification shows a MTOW of 7700 Kg for the C-212/series 300 which represents an increment of 28 % on operative weights based on re-engine programs.

Landing Distance (MLW) = 700 m

The CN-235 has been selected by Air Forces of three NATO countries: Spain, France, Turkey and it is now in selection process by USAF.

The aircraft has been also sold to several Air Forces all over the world: Saudi Arabia, Bostwana, Indonesia, Marocco, Brunei, Chile, Ecuador, Panama.

EUROFLAG

An European industrial consortium was created in 1989 by the companies: AERITALIA (Italy), AEROSPATIALE (France), British Aerospace (United Kingdom), CASA (Spain) and MBB (West Germany) in order to design and develop a new aircraft to replace the C-130 Hercules and C-160 Transall aircraft.

The Independent European Programme Group (IEPG) issued the draft of OEST for "Future Large Aircraft" (FLA) in April 1988. This OEST included the basic requirement from the Ministries of Defense of Belgium, France, West Germany, Italy, Spain, United Kindom and Turkey for a new generation tactical transport able to be converted to a tanker variant.

The main specification can be summarized as being a Tactical Transport Aircraft in the range of 20-25 Tonnes of military pay-load with long range capability in the order of 2000-2500 nm.

On this AGARD panel there are other specific papers presenting in more detail the actual status of the programme, anyway, just to give some examples, in figures 14,15 and 16 are shown alternative configurations of EUROFLAG with different powerplants and cabin dimensions.

4. CONFIGURATION ITEMS

As it is mentioned before, during the requirements analysis process trade-off studies must be performed in order to obtain a clear idea of the influence that some key parameters have over the complete aircraft configuration. The identification of the critical parameters and the evaluation of advantages or penalties to be paid for covering one or another requirement is essential to design the optimum feasible solution from both technical and economical point of view.

These trade off studies must cover a lot of configuration aspects, besides of mission and performance data; however, for an airlifter design, there are some which have a tremendous influence upon the overall configuration.

These configuration aspects are presented as follows:

- Military Loads to be transported:

  The identification of all the types of loads to be carried by the new design is the first step to be covered by the designer in conjunction with the Military authorities.

  It is essential to determine, not only the mass and geometrical data of each load, but also the priority by which it is to be transported, the number and distribution inside the fuselage cabin. This analysis allows critical loads, and also the critical points on loading operations, to be identified.

- **Fuselage Length and Cross Section:**

After the selection of the critical loads, it is neccesary to evaluate the effect on cabin design.

A trade off study between the percentage of Military loads able to be transported, and the implications in weight and fuel consumption of the configuration, must be carried out to determine the optimum one, and to identify the loads which cannot be transported without a big penalty on the overall configuration.

To present some figures of merit, for example, for a medium-large military transport design the effect of increasing 10 % in fuselage width implies an increment of 7-9 % in fuselage weight and around 3-5 % in total gross weight. Or, 10 % increase in fuselage length will imply an increment of 10-12 % in fuselage weight, and around 3-5 % in total gross weight.

- **Loading System :**

Based on the previously mentioned items and on the operational requirements for the aircraft, an assesment of the loading system must be done. This includes the to design and analizes of the rear ramp and ventral door, including the process of loading vehicles in order to determine the minimum clearances between the military loads and the aircraft structure.

It must be also considered in this study the implications and benefits to be obtained if a variable oleo extension is included in the loading operations.
As a conclusion of this analysis, the percentage of military loads versus ramp angle and sill height, will be determined.

Depending of the operational requirements, an the particular, the loading times, it may be neccesary to analizes the advantages and disadvantages of implementing a front loading system. This study must be focused on determining the penalty in weight and subsystems complexity to be paid in order to reduction on loading times.

Separate comments must be made, when considering the design of solutions incorporating a double vertical tail, in order to increase the space in the rear fuselage zone for the loading operations. This method was used, in the past, on the Packet and Noratlas designs for example, however, nowadays the weight penalty to be paid and the drag increase normally drives to design a single vertical tail.

- **Wing Design:**

One of the most important requirements for military airlifters is operation on short fields.

This requirement implies the design of a wing with sophisticated highlift devices. The determination of the efficiency of these highlift devices in order to fulfill the performances requirements versus weight and complexity needs to be done very careful job, to be able to assure that the wing design is in accorde with the real needs of aircraft operations, taking into account that an overdimension of wing area of around 5 % implies an increment in wing weight of 10 %.

- **Number and Type of engines**

The speed range required for the aircraft drives the type of powerplant to be incorporated on the configuration. For airlifter with a speed requirement up to M = 0,6 the optimum solution is normally to install turboprop engines.

When the speed is in the range of M = 0,6 - 0,67 the new single rotating prop-fans present the best performance, although the propeller efficiency could be the main problem to be analised.

In the range speed of M = 0,67-0,77 the counter rotatory prop-fan must be seriusly considered as the selected powerplant even taking into account the technological risk that the development of this type of engine carries. In this range of speed, at least on the higher margin, the utilization of turbofan powerplant is also possible, however, for the same design mission the reduction on gross weight between counter rotatory prop-fan an turbofan configuration can be evaluated in 6 - 8 % for a medium-large airlifter.

For speed range greater than M = 0,77 the best suited powerplant will be turbofan engines.

The next configuration aspect to be considered is the number of engines. It is driven by the availability of engines in the power range required, and by the reliability requirement imposed on subsystems associated with the engine and on the complete aircraft. This subject must be assessed in depth since the difference in gross weight from a configuration with two engines compared with four engines, with similar total thrust, can be in the order of 9 -11 %.

There are several other parameters to be considered during the trade-off studies before fixing the final requirements, in particular mission parameters, field and flight performances, and secondary roles to be covered by the new design. These have not been considered in this paper to emphasize the configuration parameters.

5. CONFIGURATIONS COMPARISON METHODOLOGY

During the Feasibility Phases for any new program, the normal procedure at present is to study and analyze several different configurations, designed according to the established requirements.

This means that there must be adequate tools to allow comparision of all these configurations in order to check which of them better acomplishes the required missions. Several parameters could be used to do this comparison but in the case of military transports, probably the two most important characteristics are the resulting Cost and Effectiveness for each of the configurations under study, for the missions for which they are designed.

The assessment of Life Cycle Cost versus Mission Effectiveness will provide the information necessary to discriminate between the several candidate configurations allowing studies in the following phases to be concentrated only on the most promising one.

Attention will be focused from now, in this chapter, mainly on Mission Effectiveness Analysis, due to the fact that cost analysis seems already to be better understand and it has also been the main subject of a past FMP Symposium.

Talking about military transports, two completely different utilisations can normally be expected: peacetime and wartime.

Although aircraft and fleet sizing will normally be driven by wartime requirements, it is clear that peacetime operations will compose a high percentage of the total aircraft utilisation time, so this need also to be carefully analysed in order to compare the different configurations studied. Operational effectiveness in both cases (peace and wartime) must be considered.

The configuration comparison process, could then follow the following steps:

a) Clearly, the first thing to do is to identify and define the missions to be used as bases for the study. The number of such missions must be enough to cover all the relevant aspects of the intended operations.

b) Another factor which clearly need to be carefully studied in order to get an adequate Mission Effectiveness analysis, is the definition of the expected threats during the operations of the aircraft. It means that for each mission, the definition of the scenarios in which the a/c have to operate must be started, with as accurate information as possible about distribution and number of threats, their general characteristics, etc.

   This information, used for the vulnerability/ survivability analysis, will be transformed into expected survivability figures and kill rates for every of the configurations studied, that affecting the final number for fleet sizing required to accomplish the missions, with each of the a/c.

c) After that, a careful selection must be made, of the parameters which are going to be used as a measurement of aircraft effectiveness.

   At the early stages of a program the results obtained for the Mission Effectiveness Parameters will normally allow the identification of the configuration design parameters which influence to a high degree the final result. Trade offs in these parameters will permit the selection of the best values for the final reference configurations.

d) In the end, and a result of the different factors considered previously, it will be possible then to:

   - Discriminate between the several configurations studied in a quantitative way, helping in the selection process in objective form

   - Identify the changes in the configuration design parameters which may produce an improvement in the overall effectiveness of the aircraft, in order to evaluate if it is worth or not to change them.

   - Make a preliminary assessment of the overall fleet size required to perform the intended missions in the threat scenario environment expected for the aircraft, which is in the end, one of the most important results which can be produced at the early stages of a program.

All of this however, must be done with tools suited to the preliminary phases of the program, which means that they must be fast enough to unable several different configurations be analysed in short time. It means, clearly, that the results obtained will be normally approximated as absolute values, but they still can be considered as fully valid for comparison purposes, which is the aim of the preliminary phases.

A block diagram summarizing this process is shown in figure 17.

6. SUMMARY AND CONCLUSIONS

The history and actual process followed at CASA for the analysis of the requirements and selection of the most suitable configuration for a new Military Airlifter System have been presented.

The importance of an adequate initial choice of some parameters such as fuselage cross-section and length, wing area and geometry related to load and unload operations has been emphasized.

Peace time and war time operations must be taken into account to get a realistic view of essential factors such as fleet size and life-cycle cost for the transport system.

Finally the availability of suitable powerplants is an important factor to fix the final specifications of a Military Airlifter System.

REQUIREMENT ANALYSIS

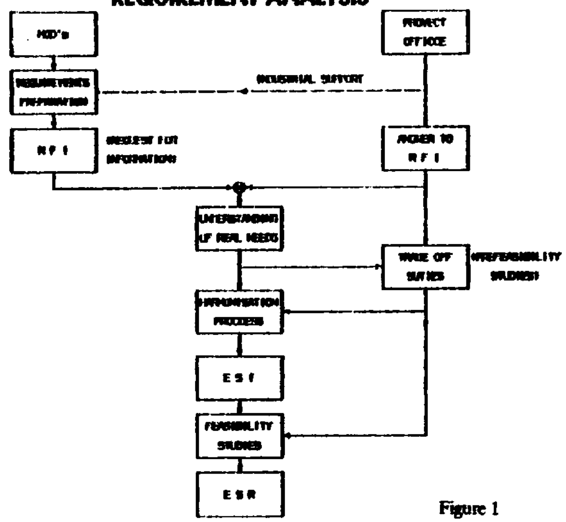


Figure 1

C-212 MAIN SPECIFICATIONS

- MULTI - PURPOSE TRANSPORT FOR JU - 52 REPLACEMENT
- EASY OPERATION AND SIMPLE MAINTENANCE
- ABLE TO OPERATE FROM UNPREPARED SHORT FIELDS
- GREAT SIMPLICITY FOR LOADING OPERATIONS
- CAPACITY FOR SMALL MILITARY VEHICLES TRANSPORT
- TRANSPORT OF 1000 Kg. (2200 lb.) PAYLOAD OVER 1000 Km (540 NM)
- MAXIMUM STATIC RANGE OF 1850 Km (1000 NM)
- MAXIMUM PAYLOAD OF 2000 Kg. (4400 lb)

Figure 2

C-212 FIRST DESIGN

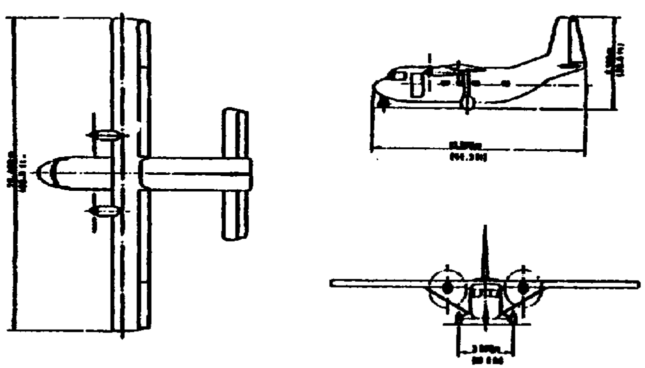


Figure 3

C-212 TRANSPORT

SELECTED CONFIGURATION

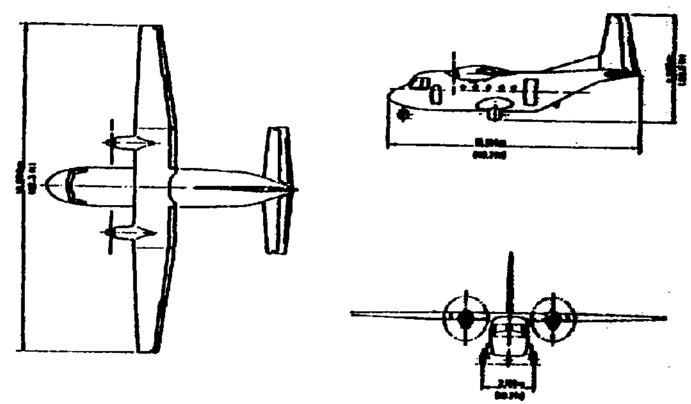


Figure 4

C-212 SERIES 300

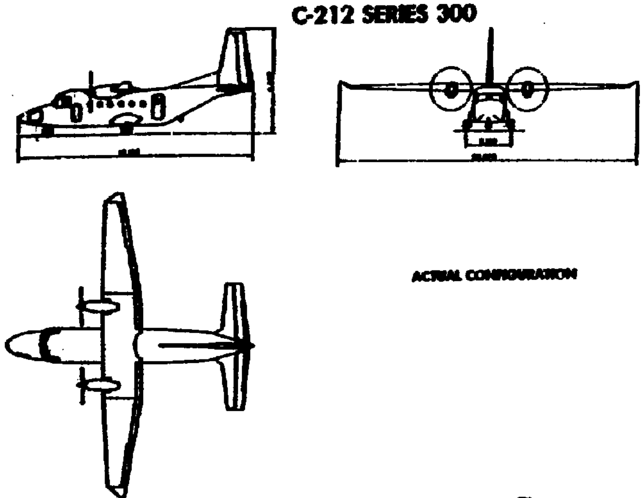


Figure 5

C - 401 MAIN SPECIFICATIONS

- MILITARY TRANSPORT FOR HEAVY LOADS AND LIGHT VEHICLES
- ABLE TC TRANSPORT PARATROOPERS AND SANITARY VERSION
- SECONDARY ROLE: AIRBORNE WARNING
- ABLE TO CONVERSION CIVIL TRANSPORT WITH STOL CHARACTERISTICS
- GREAT SIMPLICITY FOR LOADING OPERATIONS
- ABLE TO TRANSPORT AND AIR DELIVERY STANDARD PALLETS 88" X 108"
- MAXIMUM PAY LOAD GREATER THAN 5000 Kg. WITH A RANGE OF 2000 Km (1080NM)
- MAXIMUM RANGE OF 4000 Km (2160NM)
- CRUISE SPEED GREATER THAN 215 KTAS

Figure 6

C-401

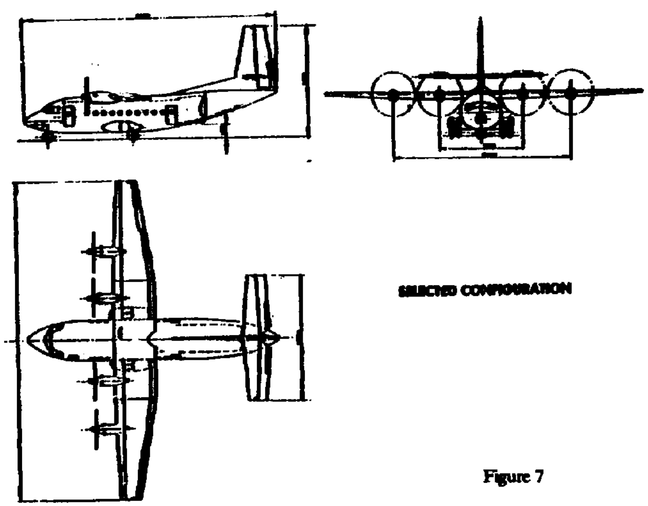


Figure 7

C-401 CROSS SECTION

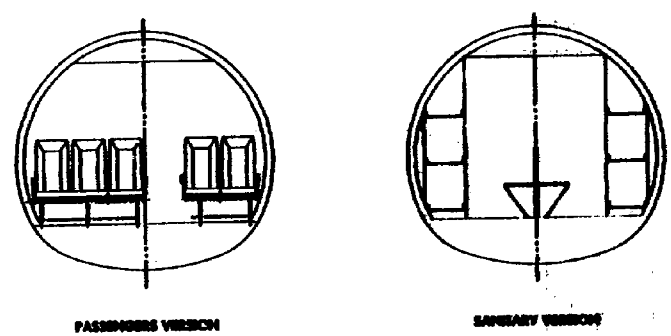


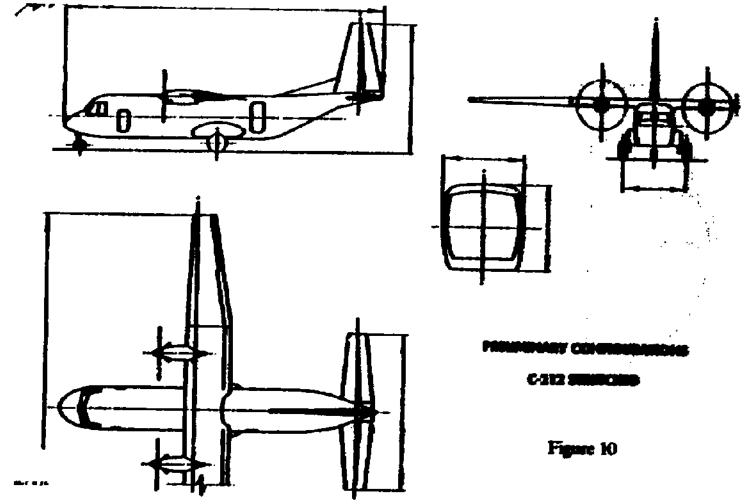
Figure 8

CN - 235 MAIN SPECIFICATIONS

- TRANSPORT AIRCRAFT FOR CIVIL/ARMY AND MILITARY ROLES
- SIMPLE OPERATION AND LOW COST MAINTENANCE
- MILITARY TRANSPORT : 3000 - 5000 Kg. PAY - LOAD
- MILITARY TRANSPORT RANGE : 400 - 500 NM
- PASSENGER CAPACITY : 30 -40 PAX
- CARGO VERSION : 4000 Kg
- AIR DELIVERY CAPABILITY
- GREAT SIMPLICITY FOR LOADING OPERATIONS

Figure 9

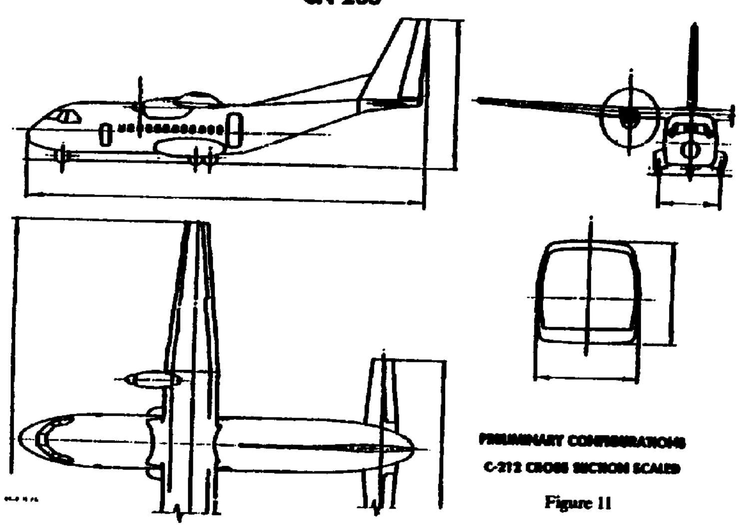
CN-235



PRELIMINARY CONFIGURATIONS
C-212 STRETCHED

Figure 10

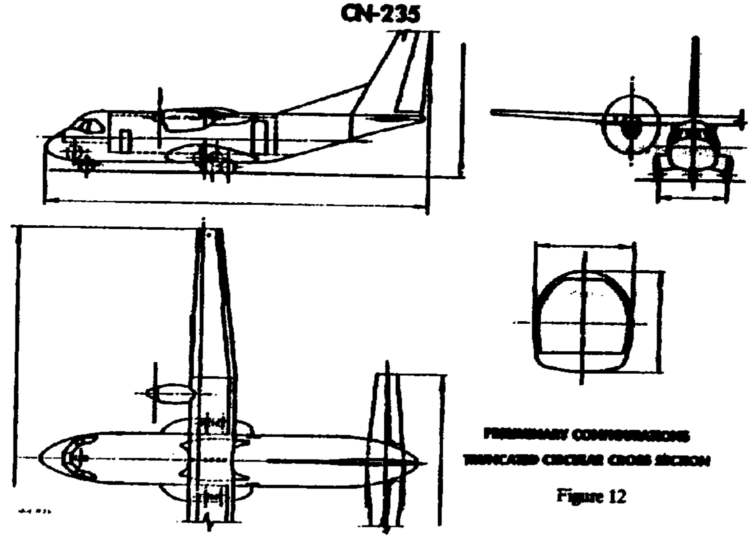
CN-235



PRELIMINARY CONFIGURATIONS
C-212 CROSS SECTION SCALED

Figure 11

CN-235



PRELIMINARY CONFIGURATIONS
TRUNCATED CIRCULAR CROSS SECTION

Figure 12

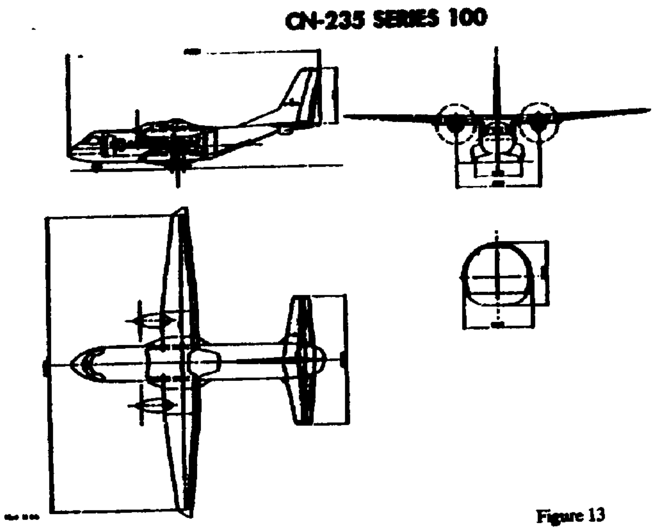


Figure 13

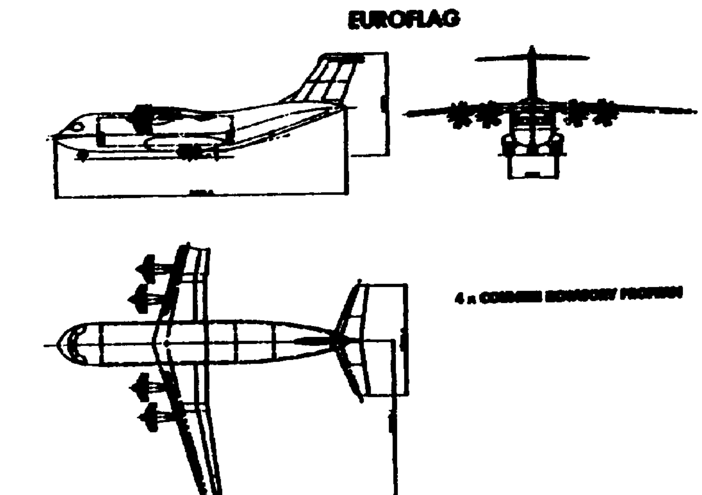


Figure 14

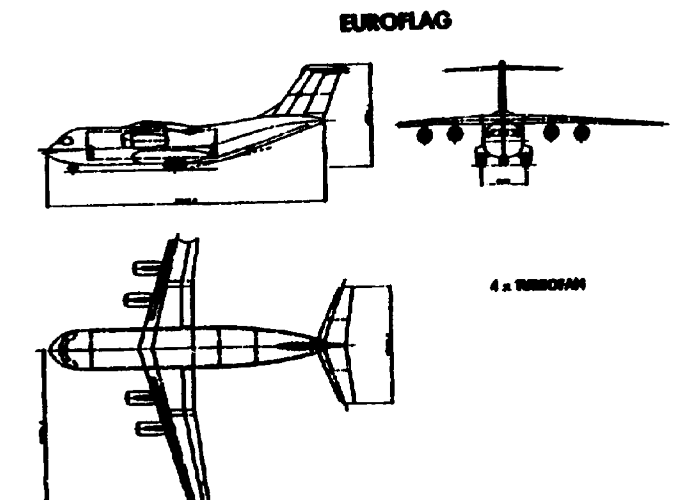


Figure 15

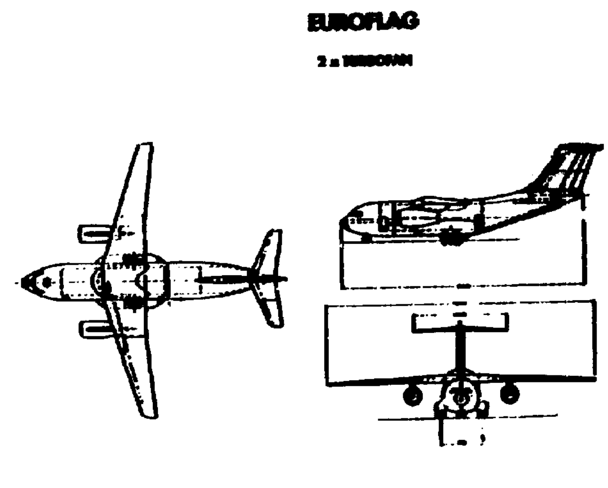
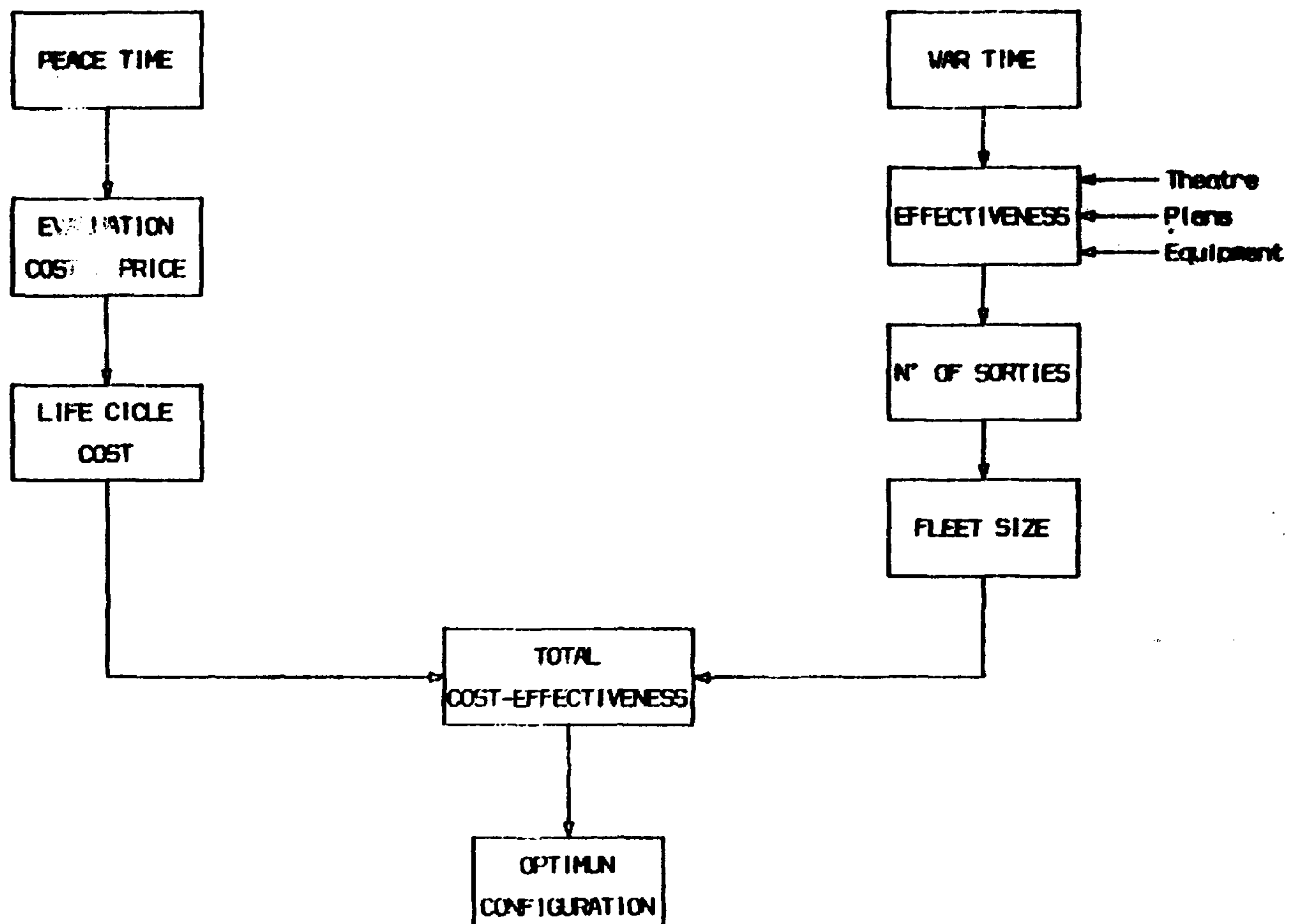


Figure 16

COST- EFFECTIVENEES ANALYSIS



Mod R 2 b.

Figure 17

ENSEIGNEMENTS TIRES PAR LA FRANCE DE SES EXPERIENCES OPERATIONNELLES RECENTES EN MATIERE DE CONCEPTION D'AVIONS DE TRANSPORT MILITAIRE

PAR
LE COLONEL BEVILLARD, SOUS-CHEF PLANS DU TRANSPORT AÉRIEN MILITAIRE
B.A. 107 - 78129 VELIZY-VILLACOUBLAY-AIR

C'EST PARCE QUE L'HISTOIRE LEUR DICTE QUE LES ARMÉES DE LA FRANCE ONT PU ACQUÉRIR, DANS UN PASSÉ RÉCENT, DES EXPÉRIENCES OPÉRATIONNELLES RICHES D'ENSEIGNEMENTS CAR TIRÉS DE THÉÂTRES AUSSI DIVERS QUE L'INDOCHINE, L'ALGÉRIE OU LE TCHAD.

AINSI FURENT ÉLABORÉS LES CONCEPTS D'EMPLOI D'UNE AVIATION DE TRANSPORT MILITAIRE, EUX-MÊMES AYANT DONNÉ NAISSANCE AUX CRITÈRES INDISPENSABLES À RETENIR QUANT À LA CONCEPTION DE FLOTTES ET D'AVIONS FUTURS.

EN EFFET, AU FIL DES NÉCESSITÉS D'UNE GUERRE TOUJOURS NOUVELLE, DE NOMBREUX MODES D'ACTIONS FURENT DÉVELOPPÉS : DES OPÉRATIONS AÉROPORTÉES AUX ÉVACUATIONS SANITAIRES, DES PONTS AÉRIENS AUX MISSIONS PLUS PARTICULIÈRES, S'IL NE FALLAIT RETENIR QU'UN SEUL CRITÈRE CE SERAIT SANS CONTESTE CELUI DE LA SOUTE.

LE COMMANDEMENT DU TRANSPORT AÉRIEN MILITAIRE (CO.T.A.M.) ET AVEC LUI L'ARMÉE DE L'AIR FRANÇAISE ONT ORIENTÉ EN CONSÉQUENCE LEUR RÉFLEXION VERS LE FUTUR ET RETENU, À L'HORIZON 2003, QUELQUES VERSIONS POSSIBLES D'UN CARGO TACTIQUE POLYVALENT LARGE D'AU MOINS 4M ET HAUT DE 3,55M, C'EST-À-DIRE DE TAILLE ANALOGUE À CELLE D'UN FIMA OU D'UN EUROFLAG.

C'EST DIRE QUE CET AVION SERA UN AVION NOUVEAU : IL NE SAURAIT ÊTRE NI UN C160 QUADRIMOTEUR NI UN C130-J MAIS DEVRA ÊTRE LE FRUIT D'UNE COOPÉRATION EUROPÉENNE POUR LE MOINS, AMÉRICANOEUROPÉENNE POUR LE MIEUX.

0. PREAMBULE

LA FRANCE, DANS SON PASSÉ RÉCENT DE L'APRÈS SECONDE GUERRE MONDIALE, A ENGAGÉ ET ENGAGE ENCORE DE MULTIPLES OPÉRATIONS LOIN DE SES FRONTIÈRES. IL FAUT VOIR LÀ UNE CONSÉQUENCE DIRECTE DE SON HISTOIRE QUI, AU-DELÀ DE LA DÉCOLONISATION, A SU LUI CRÉER DES LIENS MAIS AUSSI LUI IMPOSER DES DEVOIRS.

PARTIE DE SON OUTIL MILITAIRE S'EST FORGÉE EN CONSÉQUENCE ET C'EST AU TRAVERS DES EXPÉRIENCES OPÉRATIONNELLES RÉCENTES QU'IL FAUT ESSAYER DE TIRER LES ENSEIGNEMENTS NÉCESSAIRES EN MATIÈRE DE CONCEPTION D'AVIONS DE TRANSPORT MILITAIRE.

CETTE RÉFLEXION SERA MENÉE EN TROIS TEMPS :

1. HIER : L'INDOCHINE ET L'ALGÉRIE 1947 - 1962

2. AUJOURD'HUI : L'AFRIQUE ET LE TCHAD 1969 - 1990

3. DEMAIN : L'AVION DE TRANSPORT FUTUR 2003

1. HIER : L'INDOCHINE ET L'ALGERIE 1947 - 1962

1.1. L'INDOCHINE : 1947-1954

LES VÉRITABLES DÉBUTS DE L'AVIATION DE TRANSPORT MILITAIRE EN TANT QUE MODE D'ACTION NÉCESSAIRE AUX FORCES ARMÉES FRANÇAISES REMONTENT À LA GUERRE D'INDOCHINE, C'EST-À-DIRE 1947.

IL EST VRAI CEPENDANT QUE L'ORIGINE PROPREMENT DITE DU TRANSPORT AÉRIEN MILITAIRE DATE PLUTÔT DE 1945 ALORS QUE LA FRANCE SE VOYAIT CONFRONTÉE AU DÉLICAT PROBLÈME DU RAPATRIEMENT DE SES DÉPORTÉS ET PRISONNIERS DE GUERRE. IL S'AGISSAIT LÀ DE FAIRE FACE À UNE SITUATION D'AUTANT PLUS DIFFICILE QU'AUCUN MOYEN CONÇU ET ORGANISÉ À CETTE FIN NE SE TROUVAIT ALORS DISPONIBLE. TOUJOURS EST-IL QUE LE RASSEMBLEMENT DES APPAREILS LES PLUS HÉTÉROCLITES DU MOMENT, COMME LES ANCIENS BOMBARDIERS RECONVERTIS VAILLE QUE VAILLE, DONNA LE JOUR AU GROUPEMENT DES MOYENS MILITAIRES DE TRANSPORT AÉRIEN (G.M.M.T.A.) ANCÊTRE DE L'ACTUEL COMMANDEMENT DU TRANSPORT AÉRIEN MILITAIRE PLUS CONNU SOUS L'ACRONYME DE CO.T.A.M..

CET ASPECT DES CHOSES MÉRITAIT D'ÊTRE ÉVOQUÉ AVANT D'EN REVENIR À L'INDOCHINE. IL A EN EFFET LE MÉRITE D'ÊTRE HISTORIQUE ET DE METTRE EN ÉVIDENCE UN TYPE DE MISSION QUI, AUJOURD'HUI, TEND À PRENDRE DE PLUS EN PLUS D'IMPORTANCE : LES MISSIONS HUMANITAIRES.

ALORS, L'INDOCHINE ! LA FRANCE Y MENA UNE GUERRE LONGUE DE SEPT ANNÉES, GUERRE À DOMINANTE TERRESTRE MAIS QUI RÉVÉLA, CHAQUE JOUR DAVANTAGE AU FIL DU CONFLIT, LA NÉCESSITÉ IMPÉRIEUSE DES ACTIONS INTERARMÉES. IL S'Y EST AGI D'EXÉCUTER DES OPÉRATIONS AÉROPORTÉES, RAVITAILLEMENTS PAR AIR, PONTS AÉRIENS, ÉVACUATIONS SANITAIRES, BOMBARDEMENTS, TRANSPORTS LOGISTIQUES, OU DE V.I.P..

POUR CE FAIRE LE G.M.M.T.A. NE DISPOSAIT QUE DE JU 52, À CE POINT PEU NOMBREUX QUE DES RENFORTS AMÉRICAINS CONSTITUÉS D'UNE CENTAINE DE C47 ET D'UNE VINGTAINE DE C119 PACKETT FURENT NÉCESSAIRES : DÉJÀ L'INSUFFISANCE DES MOYENS NATIONAUX SE FAISAIT CRUELLEMENT SENTIR ! MALGRÉ TOUT, CELA N'EMPÊCHA PAS DE DÉVELOPPER DES MODES D'ACTION ADAPTÉS AUX OPÉRATIONS À RÉALISER COMME LE FURENT LES PARACHUTAGES AU-DESSUS DES POSTES ISOLÉS SANS LESQUELS ILS NE POUVAIENT SURVIVRE.

ALORS VÉRITABLEMENT LES CONCEPTS D'EMPLOI DE L'AVIATION DE TRANSPORT MILITAIRE VIRENT LE JOUR. C'ÉTAIT TOUTEFOIS TROP TARD POUR CHERCHER À LES VALIDER SUR CE QUI DEVIENDRAIT LE FUTUR CHEVAL DE BATAILLE, LE N2501 NORATLAS LIVRÉ AUX UNITÉS OPÉRATIONNELLES QUELQUES MOIS SEULEMENT APRÈS LA FIN DES OPÉRATIONS DE CE THÉÂTRE ASIATIQUE.

TOUJOURS EST-IL QUE DE CES CONCEPTS FURENT TIRÉS DES CRITÈRES NÉCESSAIRES À LA CONCEPTION D'AVIONS FUTURS ET INTÉGRALEMENT RETENUS POUR LA DÉFINITION DU CARGO POLYVALENT ACTUEL : LE C160 TRANSALL. CES CHOIX FURENT JUDICIEUX COMME LE CONFIRMA L'ENGAGEMENT SUIVANT : L'ALGÉRIE.

1.2. L'ALGÉRIE : 1954 - 1962

AUTANT L'INDOCHINE EST ASSOCIÉE À L'EMPLOI DU JU 52 (RENFORCÉ DES C47 AMÉRICAINS), AUTANT L'ALGÉRIE RESTE LE THÉÂTRE NORD-AFRICAIN D'INTENSE UTILISATION DU N2501.

AVEC CET AVION, TOUS LES MODES D'ACTION DÉVELOPPÉS À L'OCCASION DU CONFLIT PRÉCÉDENT FURENT EXPLOITÉS BIEN QUE SUR UN THÉÂTRE PROFONDÉMENT DIFFÉRENT. BIEN PLUS,

DE NOUVEAUX VIRENT LE JOUR TANT IL EST VRAI QUE, LA NATURE DES OPÉRATIONS ÉVOLUANT, L'ENGAGEMENT AÉRIEN PRIT DE PLUS EN PLUS D'IMPORTANCE AVEC L'APPARITION D'APPUI-FEU RAPPROCHÉ NON SANS CONSÉQUENCE SUR LES MISSIONS. IL S'EST ALORS AGI DE POSTES DE COMMANDEMENT VOLANT, RECHERCHE DE RENSEIGNEMENTS, ÉCLAIRAGE DE CHAMP DE BATAILLE ET HÉLIPORTAGES D'ASSAUT.

LES ENSEIGNEMENTS QUI S'EN DÉGAGÈRENT POUR LE TRANSPORT AÉRIEN MILITAIRE FURENT DE DEUX ORDRES :

AU PLAN DES TECHNIQUES MISES EN OEUVRE, IL EST APPARU QU'ELLES FURENT ADAPTÉES ET EFFICACES EN REGARD DES BUTS RECHERCHÉS. ELLES PERMIRENT DONC DE VALIDER LES CRITÈRES RETENUS EN INDOCHINE OÙ FURENT DÉVELOPPÉS NOS CONCEPTS D'EMPLOI.

EN EFFET, QU'EST-CE QUE LE SYSTÈME D'ARMES D'UN AVION DE TRANSPORT MILITAIRE, SI CE N'EST SA SOUTE ? CELLE-CI DOIT PERMETTRE DES :

- CHARGEMENTS ET DÉCHARGEMENTS RAPIDES IMPLIQUANT DES ACCÈS AVIONS PARFAITEMENT DÉGAGÉS.

- MATÉRIELS ADAPTÉS À CES CHARGEMENTS COMME LE SONT PAR EXEMPLE DES RAMPES D'ACCÈS.

- EMBARQUEMENTS DE TOUT TYPE DE FRET.

- TRANSPORTS DE PASSAGERS ASSIS OU COUCHÉS.

- PARACHUTAGES DE PERSONNELS COMME DE MATÉRIELS.

- POSTES DE COMMANDEMENT VOLANT DOTÉS DE MOYENS DE TRANSMISSIONS NÉCESSAIRES ET ADAPTÉS À LA MISSION INTERARMÉES.

- VOLS LE PLUS BAS ET LE PLUS PRÉCIS POSSIBLE, DONC DE BÉNÉFICIER D'UN MAXIMUM DE VISIBILITÉ DANS LE COCKPIT ET DE MOYENS DE NAVIGATION ADAPTÉS.

- UTILISATIONS DE TOUTES LES SURFACES POSSIBLES POUR LE DÉCOLLAGE ET L'ATTERRISSAGE, DONC D'ÊTRE SUFFISAMMENT RUSTIQUE, RÉSISTANT ET AUTONOME.

AU PLAN DE L'ORGANISATION ENSUITE ; IL APPARUT INDISPENSABLE DE DÉCIDER, À L'ISSUE DE CETTE GUERRE, LE REGROUPEMENT DES MOYENS LOURDS ET DES HÉLICOPTÈRES AU SEIN D'UN SEUL GRAND COMMANDEMENT, LE CO.T.A.M. ACTUEL.

CECI N'EST PAS SANS INFLUENCE SUR L'AMÉLIORATION DES AÉRONEFS D'AUJOURD'HUI ET LA DÉFINITION DE CEUX DE DEMAIN DÈS LORS QU'UNE MEILLEURE COHÉRENCE EST ASSURÉE. C'EST EN EFFET AU SEIN D'UN MÊME ETAT-MAJOR QUE PEUVENT ÊTRE ÉTUDIÉES LES DONNÉES TACTIQUES ET STRATÉGIQUES PERMETTANT UNE APPROCHE GLOBALE ET EXHAUSTIVE DU PROBLÈME ABOUTISSANT À LA DÉFINITION D'AVIONS LES MIEUX CONÇUS POSSIBLES EN REGARD DES MISSIONS À ACCOMPLIR.

IL FAUT AINSI TENIR COMPTE DES :

* FACTEURS ÉVOLUTIFS QUE L'ON POURRAIT CLASSER EN DEUX CATÉGORIES :

- <u>LES FACTEURS EXTERNES</u> TOUT D'ABORD, REPRÉSENTÉS PAR DIFFÉRENTES MENACES.

AU PLAN GÉOSTRATÉGIQUE ELLES EXIGENT DES FORCES ARMÉES FRANÇAISES UNE BONNE CAPACITÉ DE DISPERSION CE QUI IMPLIQUE D'ÉQUIPER LE TRANSPORT AÉRIEN MILITAIRE DE NOMBREUX CARGOS MOYENS PORTEURS DE PRÉFÉRENCE À DE GROS PORTEURS EN QUANTITÉ RÉDUITE.

AU PLAN TECHNIQUE ENSUITE, ELLES CONDITIONNENT LES CAPACITÉS D'UN AVION À SURVIVRE DANS UN ENVIRONNEMENT PARTICULIÈREMENT HOSTILE, D'OÙ LA MISE AU POINT D'ÉQUIPEMENTS PARTICULIERS AUTORISANT UNE TRÈS BONNE MANOEUVRABILITÉ EN TOUTES CIRCONSTANCES ET EN TOUTE SÉCURITÉ.

- LES FACTEURS INTERNES ENSUITE, INHÉRENTS À LA NATURE DES BESOINS MILITAIRES À TRANSPORTER MAIS TOUJOURS DIFFICILES À ÉVALUER POUR L'AVENIR. CELA RELÈVE DE LA STATISTIQUE ET CONDUIT À ARRÊTER DES COMPROMIS QUANT AUX DIMENSIONS DE SOUTE À RETENIR.

IL PEUT ÉGALEMENT S'AGIR DES MODES D'ACTION QU'IL FAUDRA METTRE EN OEUVRE ET POUR LESQUELS LES TECHNIQUES NUMÉRIQUES PERMETTENT UNE ÉVOLUTION ET UNE SOUPLESSE QUE N'AUTORISAIT PAS AUTREFOIS L'ANALOGIQUE.

* FACTEURS INVARIANTS QUI RELÈVENT AUSSI BIEN DES GRANDS ENJEUX STRATÉGIQUES ARRÊTÉS PAR LES PLUS HAUTES AUTORITÉS DE L'ÉTAT QUE DES CONTRAINTES DIVERSES D'ORDRE POLITIQUE, ÉCONOMIQUE OU TECHNIQUE RAREMENT MAÎTRISÉES PAR LES MILITAIRES. LA MOBILITÉ DES FORCES EST, POUR LA FRANCE, UN BON EXEMPLE DE FACTEUR INVARIANT QUI CONDITIONNE BIEN-SÛR L'AVION DE TRANSPORT FUTUR EN CE SENS QU'ELLE IMPLIQUE DES DISTANCES, DÉLAIS ET THÉÂTRES D'INTERVENTIONS POUR LESQUELS SERONT DÉFINIES DES CHARGES À TRANSPORTER CARACTÉRISÉES PAR LEURS NATURES , POIDS ET VOLUMES.

DE LÀ PEUT-ON ESTIMER DES DIMENSIONS DE SOUTES POSSIBLES, DES COMPLÉMENTARITÉS DE MOYENS SOUHAITABLES, DES MODES D'ACTION NÉCESSAIRES ET DES COMPOSITIONS DE FLOTTES IDÉALES.

CETTE APPROCHE SERA REPRISE PLUS EN DÉTAIL DANS LE CHAPITRE CONSACRÉ AU FUTUR. MAIS IL FAUT AUPARAVANT ABORDER LES LEÇONS D'AUJOURD'HUI.

C'EST L'OBJET DE LA DEUXIÈME PARTIE.

2. AUJOURD'HUI : L'AFRIQUE : 1969 - 1990

LA FRANCE, AU COURS DES DEUX DÉCENNIES PASSÉES, S'EST ENGAGÉE À PLUSIEURS REPRISES ET EN DIVERS ENDROITS DE CE CONTINENT. NI LA MAURITANIE NI LE ZAÏRE NE SONT EXEMPTS D'ENSEIGNEMENTS MAIS NUL MIEUX QUE LE TCHAD N'ET PLUS APPROPRIÉ POUR TÂCHER DE FAIRE LA SYNTHÈSE DES EXPÉRIENCES OPÉRATIONNELLES ACQUISES. IL OFFRE EN EFFET L'AVANTAGE D'UNE CERTAINE CONTINUITÉ DANS LE TEMPS ALORS MÊME QUE, LA NATURE DES MENACES ÉVOLUANT, LES MODES D'ENGAGEMENT SE TRANSFORMÈRENT, NON SANS CONSÉQUENCE POUR L'AVIATION DE TRANSPORT MILITAIRE ÉQUIPÉE POUR CE FAIRE DE DC8 GARANTISSANT L'ÉCOULEMENT DU FLUX LOGISTIQUE ET DE C160 TRANSALL PLUS ADAPTÉ AUX MISSIONS À CARACTÈRE TACTIQUE.

POUR COMMENCER, IL CONVIENT DE RÉFLÉCHIR SUR LA PÉRIODE 1969 - 1974 DES PREMIÈRES OPÉRATIONS, CE DÉCOUPAGE N'AYANT RIEN D'ARBITRAIRE MAIS REFLÉTANT UNE ACTIVITÉ ORIENTÉE À SON DÉBUT VERS UN SUPPORT DE NATURE PRINCIPALEMENT LOGISTIQUE.

2,1 LES PREMIÈRES OPÉRATIONS : 1969 - 1974

A L'OCCASION DES PREMIERS ENGAGEMENTS IL S'EST ESSENTIELLEMENT AGI, COMPTE TENU DE LA NATURE DES MENACES, DE FOURNIR UN SUPPORT LOGISTIQUE AU DISPOSITIF DE NATURE PUREMENT TERRESTRE ALORS MIS EN PLACE.

Y FURENT CONFIRMÉS LES CHOIX FAITS SUR C160 EN MATIÈRE DE :

- SOUTE : APTITUDE À TOUS LES TRANSPORTS POSSIBLES ET DE FAÇON AUTONOME.

- **Avions** : capacité aux terrains sommaires et au travail en conditions très austères (chaleur, sable, ...) autonomie de la navigation et de la mise en oeuvre, avantage de la vitesse, grande manoeuvrabilité, etc..

Mais déjà **des insuffisances** se confirmèrent comme :

- la faiblesse du parc aérien (inexistance de gros porteurs à long rayon d'action).

- le manque de visibilité dans la cabine.

- la modestie des capacités logistiques en termes de charges offertes/distances franchissables.

- la nécessité au niveau du théâtre (niveau tactique) de disposer d'avions stations relais de transmissions pour les opérations engagées.

Les trois premières remarques serviront d'enseignements pour l'avion de transport et la flotte futurs. C'est en effet un peu tard pour le C160 encore que la relance de cet avion en 1980 a permis de développer une version ravitailleurs/ravitaillés améliorant sensiblement, à charge constante, les distances franchissables.

La quatrième quant à elle a permis de développer une version C160 poste de commandement (P.C.).

En résumé ces premières opérations au Tchad ont permis de mettre en évidence des insuffisances déjà prises en compte (ou qui le seront) pour l'avion de transport futur mais aussi de valider la parfaite adaptation du nouveau porteur C160 au travail dans des conditions difficiles (parachutages, vols basse altitude, terrains sommaires, mise en oeuvre, fiabilité, autonomie, etc.).

Il faut cependant y ajouter un enseignement supplémentaire déjà tiré des actions antérieures mais particulièrement confirmé sur ce théâtre, à savoir, la nécessité de disposer **d'équipages polyvalents**, rompus à toutes techniques, donc très bien formés et **très bien entraînés** imposant la mise au point, aujourd'hui déjà mais demain plus encore, de simulateurs de missions des plus évolués.

Qu'en est-il maintenant de la période actuelle ?

2,2. Les opérations suivantes : 1974 - 1990

La **nature** des opérations connut une **nette évolution** en raison de l'apparition de **nouvelles menaces** découlant des **nouvelles capacités** développées par certains pays, notamment en matière de **guerre aérienne**.

Purement **terrestres** à leur origine, les dispositifs devinrent de plus en plus interarmées, la composante aérienne s'affirmant chaque jour plus indispensable bien qu'évoluant dans le temps.

En effet, et pour des raisons essentiellement **politiques l'offensive** dut céder progressivement le pas à la **défensive**, la **dissuasion** (cette fois-ci dans le sens du **fort au faible**) devenant l'objectif principal, s'appuyant sur des moyens de **défense aérienne** importants accompagnés de moyens de **retorsion** significatifs.

Mais quelles conséquences cela entraînait-il pour l'aviation de transport militaire ?

A) La nouvelle politique ainsi fixée fut à l'origine d'une brusque augmentation des charges à transporter puisqu'il s'agissait alors de mettre en place des systèmes cohérents organisés autour des composantes :

RADARS + AVIONS + MISSILES

Les poids et volumes n'étaient plus à la seule dimension de la soute du C160 gravement mise en défaut.

B) Le théâtre d'intervention et l'évolution des forces en présence furent la source de grandes difficultés en matière d'autorisations de survols de certains pays dont la volonté de neutralité ne peut qu'être respectée. De ce fait cependant les distances à franchir furent plus proches de 7000 km que de 3000 km. La encore le C 160 n'était plus adapté et il faudra en tirer les leçons pour l'avenir.

C) De ce qui précède il faut comprendre que l'affrètement de gros porteurs civils devint absolument nécessaire, dénotant une fois encore l'insuffisance du parc avions du CO.T.A.M.. Bien plus, une grande partie des cargos tactiques C160 durent être mobilisés pour apporter au plus près des zones d'utilisation, les grandes quantités de matériels débarqués sur les gros aéroports seuls susceptibles d'accueillir les gros porteurs. Cet enseignement est essentiel en matière d'avion de transport futur qui devra donc pouvoir intervenir sur de grandes distances et directement vers les théâtres d'engagements. Son aptitude à pratiquer des terrains courts et sommaires sera donc un critère rédhibitoire.

D) L'absolue nécessité des moyens de transmissions non plus seulement adaptés au théâtre (niveau tactique) mais, et c'est nouveau, permettant le dialogue direct et discret au niveau opératif. Cet aspect est aujourd'hui à l'étude.

E) L'adaptation inévitable des moyens de recueil du renseignement mais pour lesquels les remèdes adoptés ne font pas l'objet de cette étude.

F) L'évolution indispensable des modes d'action notamment en matière de vols tactiques, largages ou posers d'assaut de nuit. Les techniques nécessaires pour y parvenir sont maintenant au point et intégralement prises en compte pour la conception de l'avion de transport futur.

G) L'apparition d'une mission nouvelle et indispensable au profit des avions de chasse: le ravitaillement en vol notamment en basse altitude. Les C160 NG (nouvelle génération) sont aujourd'hui aptes au ravitaillement de tout avion de combat de l'armée française et l'avion de transport futur le sera.

H) Le développement des moyens nécessaires pour affronter la menace sol-air. Il s'agit bien évidemment de moyens de détection qu'il est inutile ici de détailler et de leurrage actuellement mis au point sur C160. Pris dès le stade de la conception sur l'avion de transport futur ils seront davantage intégrés qu'ils ne le sont aujourd'hui.

I) Au Tchad aussi ont été validés tous les critères précédemment définis en matière de polyvalence et d'entrainement des équipages mais aussi en termes de complémentarité de la flotte aérienne, d'autonomie et de précision des moyens de navigation. Il en est un nouveau, du moins peu évoqué encore à ce jour pour les avions de transport: les systèmes de préparations de missions. Ils deviennent impératifs dès lors que le facteur rapidité d'intervention conditionne la réussite politique de l'entreprise.

Le COTAM travaille à l'heure actuelle sur de tels systèmes ceci en cohérence complète avec un vaste programme, aujourd'hui financé, de rénovation de ses C160 Transall.

Telles sont donc les réflexions actuelles de l'Armée de l'air française qu'il convient maintenant de projeter dans le futur. C'est l'objet de cette troisième et dernière partie.

3. DEMAIN : L'AVION DE TRANSPORT FUTUR 2003

3,1. Préambule

Le besoin initial de cet avion était exprimé pour 1995 mais les nombreuses contraintes évoquées plus haut ont conduit à repousser ce programme au-delà de l'an 2000 tout en assurant la survie des Transall de première génération en cohérence avec les nouveaux objectifs fixés.

Quoiqu'il en soit leur remplacement est inéluctable et, dès à présent, le Commandement du transport aérien militaire a défini ce que devraient être les principales caractéristiques de l'avion de transport futur (A.T.F.).

Il a précisé notamment les dimensions idéales de la soute, le nombre et la nature des vecteurs à mettre en ligne pour que soient satisfaits les besoins globaux de la France en termes de capacité de transport aérien militaire.

Mais ce travail n'a pas été élaboré isolément. Il est le fruit d'une collaboration étroite au niveau interarmées et les principales conclusions du groupe de travail constitué à cet effet sont données ci-après.

3,2 Méthode

- La démarche adoptée a été la suivante : caractériser les dimensions de l'A.T.F. à partir de divers scénarios dont le regroupement en concepts permettrait d'en évaluer le nombre indispensable à acquérir.

- L'élaboration des scénarios a été le fruit du regroupement de divers paramètres de situation en cinq familles : théâtre d'intervention (par exemple la France ou l'Outremer, etc.), contexte (neutre ou hostile), missions (engagement, soutien, spéciale,...), profil (basse altitude, haute altitude) et objectif (parachutage, atterrissage), chacun des paramètres retenu comparé à tous les autres permettant de dégager des schémas types de missions selon la vraisemblance de leur occurrence. Ainsi, ne saurait être retenu le largage très grande hauteur à l'occasion d'évacuation sanitaire en France !...

- Un certain nombre de scénarios (11) ont ainsi été validés par théâtre, comme l'engagement d'une grande unité terrestre en Europe ou l'évacuation de ressortisants français d'un pays ami.
  Replacés dans des situations stratégiques (ou concepts d'engagement) définies au nombre de 5 (ex : assistance opérationnelle à un pays ami), leur taux de vraisemblance a pu être évalué. (Par exemple, le "redéploiement de sûreté initiale" (scénario) n'est pas vraisemblable dans le concept "assistance opérationnelle à un pays ami").
  De là ont été repertoriés les matériels et personnels à transporter pour chaque type d'intervention et définis, en fonction des caractéristiques spécifiques des missions à exécuter, trois types de cargos, ATF0, ATF1, ATF2 possibles.

- A partir de ces hypothèses, concept par concept, il a fallu calculer la taille de la flotte à prévoir. Toutefois des aménagements tenant compte des différentes contraintes, politiques et économiques notamment, ont été apportés (ainsi deux concepts ne peuvent être joués simultanément) ; il en est ressorti que la flotte de référence était celle correspondant au concept le plus pénalisant. En outre la participation de gros porteurs de la classe C17 a été envisagée.

- Finalement, l'étude a débouché sur une flotte souhaitable, en 2010 d'environ 80 ATF, 4 A340 et 6 C17, cet A.T.F. offrant une soute large d'au moins 4m et haute de 3,55m.

- Les caractéristiques principales de cet aéronef résideront dans ses grandes capacités tactiques tout temps : capable d'intervenir vite et loin, d'opérer en autonomie sur des terrains de 1000m, sommairement aménagés, susceptible d'utiliser tous les modes d'action connus à ce jour, en toute sécurité, et de s'adapter aisément aux développements de techniques nouvelles, il sera le reflet exact de toutes les leçons apprises sous tous les cieux et sur tous les terrains par le transport aérien militaire français.

CONCLUSION

Ce sont les conflits dans lesquels la France s'est engagée après guerre qui ont permis d'arrêter les concepts d'emploi d'une aviation de transport militaire, concepts ayant à leur tour entraîné la définition des critères impératifs devant intervenir dans la conception d'avions futurs.

Déjà largement validés sur C160 Transall ils évoluent néanmoins en même temps qu'évoluent la nature et le volume des interventions menées, elles-mêmes découlant de l'accroissement des menaces rencontrées.

Plusieurs d'entre-eux ont déjà été pris en considération, sur la relance des Transall en 1980 et la rénovation amorcée pour 1992. Mais certains ne sauraient l'être que dans l'avenir : ils dimensionnent à la fois l'avion futur en termes de capacités et performances mais aussi la flotte future en termes de complémentarité et de quantité.

Ainsi, au stade actuel des réflexions du CO.T.A.M. et à l'horizon 2010, le parc avions du transport aérien militaire français devrait se situer autour de 80 ATF, 4 à 6 C17 et 4 A340 Militarisés.

Les caractéristiques essentielles de cet A.T.F. seront :

- Sa soute qui devra présenter une hauteur minimale de 4m et une largeur minimale de 4m bien supérieures aux dimensions actuelles des C160 et C130.

- Ses grandes capacités tactiques tout temps alliées à son rayon d'action important.

- Son interopérabilité dès lors que cet avion ne verra le jour qu'en coopération européenne pour le moins, américano - européenne pour le mieux.

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RECENT IMPROVEMENTS TO THE RAF AIR TRANSPORT FORCE

by

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INTRODUCTION

1. This paper will describe the most significant improvement to the United Kingdom's Military Air Transport Force in recent years. That is the procurement of the Lockheed L1011 Tristar aircraft into RAF service. The reasons behind the introduction of the Tristar, and its subsequent modification into three very capable tanker, freighter and passenger carrying variants will be outlined. Moreover, some of the aircraft's capabilities and drawbacks will be discussed. In addition, and with a view to the future, some of the cost disadvantages of an aging air transport fleet will be considered. Furthermore, the RAF approach to considering a timescale for the introduction of a possible replacement transport aircraft will be presented. (25) * Military aircraft * Jet transport aircraft

LOCKHEED TRISTAR

2. Background. Up until 1982, it had been envisaged that the United Kingdom's Air to Air Refuelling (AAR) tanker fleet would comprise the Victor K2 (a converted bomber aircraft) and the VC10 K. These aircraft were planned to serve up until the end of the century, when a new multi-role tanker/transport aircraft could assume the role. However, the Falklands Campaign of 1982, which relied heavily on the RAF transport and tanker assets, rapidly used up much of the Victor K2 remaining fatigue life. In addition, the conflict also established a long term demand for more transport/tanker capacity, for the long range intervention or reinforcement roles. In 1982, one short term measure to augment the AAR Force was to convert 6 C130 aircraft to single point tankers. For the longer term, it was decided that a new aircraft, similar to the USAF KC10, had to be procured.

3. Procurement. Late in 1982, due to a slump in the civil air transport industry, there were many cheap surplus airliners on the commercial market. Two groups of aircraft were identified as being suitable for the RAF needs, the DC10 (ex bankrupt Laker airways) and the Tristar (ex British Airways and Pan Am surplus aircraft). Both aircraft types were studied, and although it might have been supposed that the existence of the KC10 tanker derivative of the DC10 would have given that type the edge, there would in fact have been little read across to the civil aircraft conversion. Eventually, the Tristar emerged as the most suitable aircraft for the RAF's planned conversion. Six ex British airways, and three ex Pan Am aircraft were purchased in 1983/84, giving the RAF a fleet of 9 relatively low hour wide bodied aircraft.

4. Required Aircraft Roles. Although it was the need to augment the RAF's Tanker Force that initially drove the acquisition of the Tristar, the aircraft are also required as freighters and passenger carriers.

5. Aircraft Variants. The Tristar modification programme, carried out by Marshalls of Cambridge Engineering, is approaching completion and has resulted in the three variants described in table 1

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TABLE 1

No of A/C	RAF Desig	Modifications
2K	Mk 1	- AAR probe fitted. - Additional fuel tanks fitted into the underfloor freight holds. - Forward main cabin fitted with a freight floor, for baggage stowage. - Centre line mounted twin AAR HDUs fitted.
4	KC Mk 1	- AAR Probe fitted. - Additional fuel tanks fitted into the underfloor freight holds. - Large freight door fitted in fuselage side. - Freight roller floor fitted in the main cabin. - Centre line mounted twin AAR HDUs fitted.
3	C MK 2 (K)	- AAR Probe fitted. - Basic airline configuration retained, but wing mounted AAR pods will be fitted, to give away basic fuel only.

6. Tanker Conversion. The KMk1 and KCMk1 tanker conversion was accomplished by the following aircraft modifications:

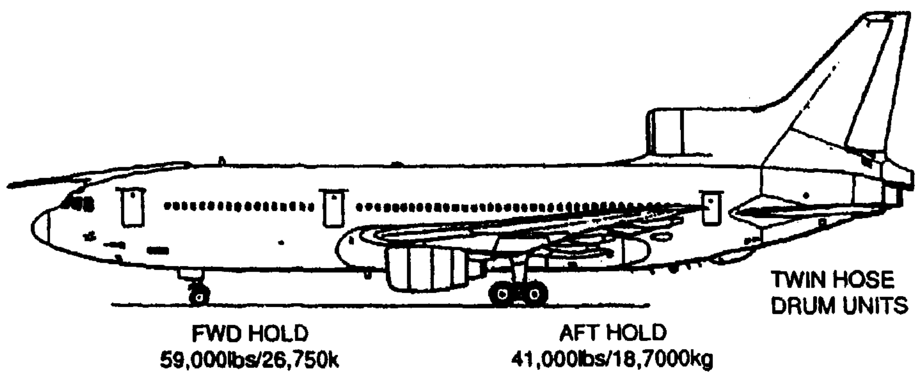
a. Underfloor Freight Hold Tanks. In order to be an effective AAR tanker aircraft, additional fuel capacity was required. So it was decided to install fuel tanks in the underfloor freight holds. Seven fuel cells were built to the same dimensions as standard airline baggage containers, so that they could be inserted through the existing hold doors, into the forward and aft holds. This provides the capacity for an additional 100,000 lb (45,500 kg) of fuel. Moreover, the aircraft's existing fuel system was modified, and extra fuel pumps fitted, to enable all tanks (in the wings and holds) to either give or receive fuel in flight.

b. Airframe. Because the under-floor fuel cells contain a greater weight than the holds original design capacity, the compartment floors had to be strengthened, and frame reinforcing straps fitted externally.

c. Hose Drum Units. Two Flight Refuelling Hose Drum Units (HDU) have been fitted into the rear of the aft freight hold. Only one HDU can be deployed at a time, but two units provide for redundancy. A new pressure bulkhead had to be built around the HDUs, as these units function unpressurised. Each HDU is capable of deploying up to 70 ft (21.3 m) of hose, and can deliver fuel at a rate in excess of 4000 lb per minute.

d. Flight Deck. The bulkhead at the rear of the flight deck had to be moved 16 in (0.4 m) aft to accommodate an enlarged flight engineers panel, from where fuel dispensing operations are controlled. A closed circuit TV system is provided for the flight engineer to monitor the receiver aircraft's progress.

e. AAR Probe. For maximum flexibility, all 9 aircraft were fitted with refuelling probes. The probe is mounted above the flight deck, offset to the right, above the co-pilot's seat. The fuel is routed into the aircraft aft of the flight deck, and connects with the aircraft fuel system in the mid-section. The probe is declined 7° below the aircraft's datum to allow for the nose up attitude experienced at typical refuelling speeds.



TOTAL ADDITIONAL FUEL : 1000,000lbs/45,4000kg
TOTAL FUEL LOAD INC WINGS 213,240lbs/96,7000kg

Fig 1 illustrates the location of the underfloor fuel tanks and Hose Drum Units:

7. Aircraft Drag. Overall, the external modifications increase the aircraft's drag by 7% at cruise speed. Half of this additional drag derives from the probe. Therefore, and if required, the probe can be removed and replaced by a flush fitting blanking plate.
8. Cabin Configurations. Each of the three Tristar variants has a different cabin configuration as follows:

a. K Mk 1. This variant retains 204 of the original airline seats in the centre and aft sections of the main cabin, in a 3-4-3 fit. Because the freight hold now contains fuel, provision is made for passenger baggage in the forward cabin. The baggage is put in specially designed containers which are loaded through the mid- section passenger door. The freight section of the cabin has a roller floor, and a removable ball mat can be fitted inside the door to assist container loading. The total baggage capacity is 25000 lb (11365 kg) in 33 containers.

b. KC Mk 1. This freighter variant is fitted with a large cargo door in the upper left side of the fuselage, which provides a clear opening of 140 by 102 inches (3.56 m by 2.59 m) above the cabin floor level, when the door is raised. The door is operated by hydraulic powered jacks, which are independent of the aircraft's other hydraulic systems, with a back up manual pump. The modification to install the cargo door was complex and involved cutting out a large section of the fuselage side, after considerable internal jigging had been fitted to ensure that the original shape was retained. Then the door frame, or module, which included the door aperture, hatches, operating jacks and hydraulic pump, was grafted on to the fuselage. Furthermore, the cabin floor was substantially strengthened and fitted with roller conveyor, in order to accept pallets of up to 10,000 lb (4545 kg) each, in the heavy duty central section. A ball mat is fitted adjacent to the cargo door to assist the manoeuvring of large loads through the aperture. A total of 20 standard 108 by 88 inch (2.74 by 2.24 m) pallets can be carried, with a maximum payload capacity of 95000 lb (43000 kg). Four internal winches are provided to assist the onloading and positioning of freight. The flexibility to revert to the passenger role is retained by having custom built pallets fitted with passenger seats, galleys or aeromedical equipment. The role changing of this variant is, therefore, simple and permits variable ratios of passengers and freight. A maximum number of 194 palletized seats can be fitted, 9 abreast, which leaves 3 pallets available for passenger baggage. In this role, passenger emergency oxygen systems are fitted in the seats, as the airline overhead luggage bins have been removed to provide more freight space. In order to provide crew crash protection when carrying freight, a heavy duty restraint net is fitted at the forward end of the cabin.

TRISTAR KC Mk1

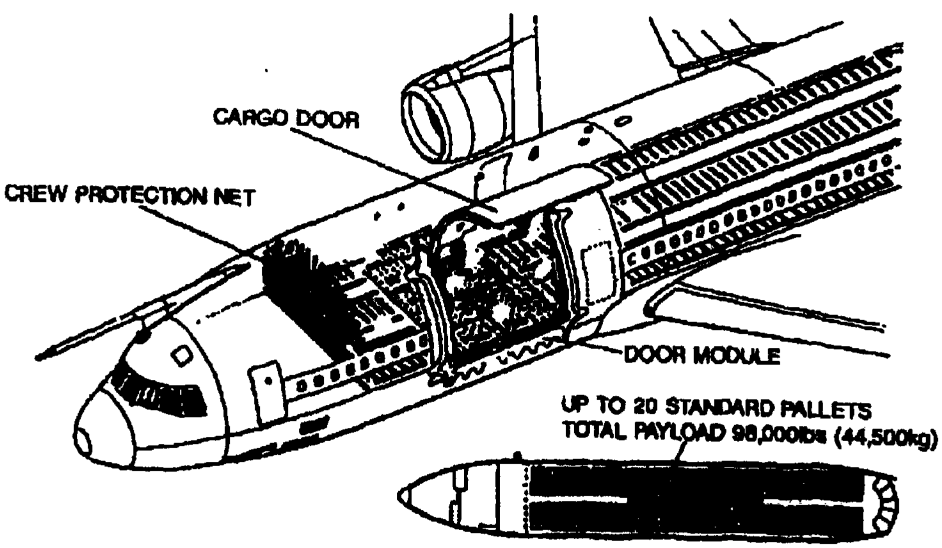


Fig 2 illustrates some of the structural modifications to the KCMk

c. C Mk 2 (K). The 3 aircraft of this variant will essentially remain in the airline passenger fit, with no additional fuel tankage. However, they will be fitted with wing mounted AAR pods to enable the aircraft to give away a proportion of its basic wing fuel.

9. Aircraft Performance. The Tristar in RAF service has a maximum all up weight (AUW) of 540,000 lb (244,950 kg), compared with the 504,000 lb (228,615 kg) of the standard airline version. This AUW increase does not derive from any structural modifications, but is accomplished by reducing the in-flight G limit from 2.5 G to 2.0 G, and is required to permit the aircraft to operate with its full fuel load. The penalty for operating at the higher gross weight, is that the balanced field take off distance required is increased from 9300 ft (2835 m) to 10000 ft (3050 m). Therefore, there are relatively few military airfields in Europe where a fully laden Tristar could take-off. However, the aircraft will operate at lower weights from smaller airfields, and then top up as required, using the Tristar's own refuelling probe. As a passenger or freight carrying aircraft, the underfloor fuel tanks will normally remain empty, and operate at weights up to 510,000 lb (321,336 kg). With a payload of 95,000 lb (43,092 kg), and using wing fuel only, the Tristar has a range of 4,200 mm (7,780 km). The aircraft has a relatively high long range cruise speed of MO.83, and a normal cruise speed of MO.85. However, these speeds are reduced when operating above the normal 504,000 lb (228,615 kg) AUW. When in the tanker role, the Tristar can refuel aircraft over a speed range of 180 - 320 kts IAS/MO.84, at altitudes up to 35,000 ft. Moreover, it has 124,000 lb (56,266 kg) of fuel available for offload at a range of 2,300 mm (4,260 km) from base.

10. Operating Problems. Generally, all the Tristar variants have proved to be valuable and flexible air transport aircraft. However, several problems have been encountered in service, some were foreseen, some not. Most of the drawbacks derive from the basic design of modern wide bodied jets. As a tanker, the Tristar clearly has a large amount of fuel available for offload. However, at present none of the aircraft are yet fitted with the planned wing AAR pods.The delay in this, the final stage in the Tristar modification programme, is due to a temporary incompatibility between the AAR pod and the planned wing mounting point. So for the immediate future, the Tristar will remain a single point tanker, which can cause delays when large numbers of fighter aircraft are queuing up to be refuelled. The Tristar can refuel all RAF AAR capable aircraft, however, some difficulties have been encountered by C130 receiver aircraft. At the relatively low C130 refuelling speed of 200 kts, the Tristar produces a large downwash which deflects the C130 2° down. Therefore, for a C130 to onload a typical 30,000 lb (13,636 kg) of fuel, the refuelling formation has to enter a toboggan manoeuvre from 25,000 ft to 8,000 ft. The Tristar is limited to operating from major air bases due to the high pavement strength required for runways and taxiways, and the large amount of ground loading equipment required to raise freight 15 ft (4.57 m) to the cargo floor. This latter drawback could be solved by fitting an internal cargo loading gantry, which is under consideration.

FUTURE AIR TRANSPORT AIRCRAFT

11. Background. One problem which will be encountered by most of the NATO air forces, is that of aging air transport aircraft. The RAF C130 and VC10 transport fleets are approaching 25 years of age. Although these aircraft have flown fewer hours and cycles than their civilian counterparts, metal fatigue and corrosion are problems of accelerating importance. The present aircraft could be kept in service for perhaps a further 25 years, but at an ever increasing cost. Clearly, it will be economic to replace these aircraft when the cost of running the present fleet exceeds the cost of purchasing, maintaining, and operating new aircraft. Therefore, the RAF has instigated a 'Cost of Ownership Study', which will estimate the cost of maintaining the viability of the C130 and VC10 fleets for a further 25 years. The cost advantages accruing from purchasing new aircraft derive from the following savings:

a. Fewer Aircraft Required. Fewer of the next generation of transport aircraft can provide the same airlift capability as existing large fleets, as they will have superior performance and possibly larger freight compartment dimensions. New construction methods and increased component reliability mean that new aircraft will spend less time under maintenance, whilst the present aircraft will need increasingly more refurbishment.

b. Reduced Manpower. Future aircraft would reduce manpower requirements; fewer numbers of more serviceable aircraft will substantially reduce the number of ground personnel needed. Moreover, the new aircraft are likely to be crewed by only 2 pilots and one loadmaster, so fewer aircrew will be required. However, for some roles, it may be an advantage to retain a small number of navigators.

c. Reduced Operating costs. The annual operating costs for a fleet of new aircraft, with an equal airlift capability to the present fleet, will be substantially lower due to better aircraft performance, fuel efficiency and manpower savings.

12. Timing of Fleet Replacement. The timescale for the replacement of the present air transport fleet is as yet not determined, as the results of the 'Cost of Ownership Study' are yet to be analysed. However, there are other pertinent factors such as changing defence requirements and budget constraints. For instance, if a smaller transport fleet is called for, then the existing aircraft could possibly be made to serve longer. On the other hand, if the present capability is to be maintained, replacement aircraft would be needed earlier.

13. Likely Replacement Aircraft. When the timescale for the replacement of the current RAF transport fleet is fixed, the new aircraft will be selected on a cost effective basis from the available contenders. Possible replacement aircraft include the following:

a. C130 J. The J model C130 is a relatively straightforward update of the well proven C130 E/H. It is forecast to be available at comparatively low unit cost. The advantage of the C130 J is that it has an improved payload/range capability, better short field performance, and should be available within the next 6 years. However, the J model will have the same load limiting freight bay cross section of the present C130.

b. EUROFLAG. The European Future Large Aircraft promises a superior airlift capability to the C130 J. However, the earliest in service date of this aircraft is likely to be into the next century, and at a relatively high unit cost.

c. Advanced Tactical Airlifter. Various large US aircraft manufacturers have proposed designs for a new "Super-STOL" advanced tactical transport aircraft. These designs are still in the concept stage, however, the aircraft is forecast to have a superior capability to the C130 and, if the USAF support the programme, a relatively low unit cost.

CONCLUSION

14. The procurement of the Lockheed Tristar into RAF service, and its subsequent modification into an AAR tanker and an extremely capable freight carrying aircraft has been relatively straightforward. Moreover, by maintaining a range of three variants, and the ability to re-role the freighters into passenger carriers, the fleet is proving to be a flexible asset to the RAF air transport force. The aircraft are very cost effective, by virtue of the fact that at the time of purchase, surplus airliner prices were depressed. The limitations of the large wide bodied aircraft design have caused some problems, such as the amount of ground handling facilities required, and airfield pavement limitations. However, as a strategic air transport and AAR tanker aircraft, the Tristar has proved a success.

15. The RAF, along with many other air forces, is facing the problem of an aging air transport fleet, with its C130 and VC10 aircraft nearly 25 years old. At present a cost analysis is being conducted to decide a timescale for the introduction of a new transport aircraft. When the time for a replacement is determined, the most cost effective aircraft will be selected from the available options.

C-130 ELECTRONIC COCKPIT
RELIABILITY AND MAINTAINABILITY TECHNOLOGY INSERTION PROGRAM (RAMTIP)

AD-P006 245

by
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SUMMARY. The Reliability and Maintainability Technology Insertion Program (RAMTIP) is aimed at accelerating new technologies from the laboratory and applying them to Air Force weapon systems in an effort to improve reliability and maintainability (R&M). This RAMTIP project will replace some sixty analog type cockpit instruments in a Military Airlift Command (MAC) C-130E with six liquid crystal flat panel displays. Five displays will be installed on the pilot's/copilot's instrument panel with a sixth display installed at the navigator's station. Designed in the mid-1950's, the C-130 has remained highly cost effective to procure and operate. This is due largely to the simplicity of its systems and the fact that its design and tooling costs have long since been amortized. The aircraft performs a diversity of missions quite well, but the repairing and stocking of obsolete analog type instruments has become logistically difficult and costly. The purpose of this project is to demonstrate the operational effectiveness and suitability of active matrix liquid crystal flat panel displays in the C-130 and to validate the projected R&M improvements of this technology over electromechanical analog instruments and cathode ray tubes (CRT). Although work is still in progress on this project, the successful development and integration of this technology offers significant potential improvement in R&M, redundancy with graceful degradation, and enhanced operational effectiveness. Once proven, this technology can be applied to a wide variety of other aircraft throughout the Air Force inventory and other Department of Defense services, as well as that of the commercial aircraft industry. (25) * Jet transport aircraft,

BACKGROUND. * Cockpits, C-130 aircraft.

C-130 Aircraft. The C-130 has achieved worldwide recognition as a cost-effective, reliable airlifter. It is operated extensively by the U.S. Armed Forces, as well as some 63 foreign countries. The current MAC C-130 force is planned to be the primary U.S. theater airlift aircraft well into the 21st Century. It will be complemented by both the C-17 aircraft, to be operational in the mid-1990's, and the Advanced Theater Transport (ATT), to be introduced sometime after 2008. The C-130 has met the airlift challenge since the mid-1950s, even as Army and Air Force demands for tactical airlift have steadily increased. The majority of MAC's C-130Es were purchased in the early 1960s.

With an average aircraft service life approaching 25 years, avionics systems in the aging MAC fleet are becoming increasingly difficult to maintain and expensive to operate. The repair and stocking of obsolete analog-type instruments particularly have become very difficult and costly. Sources of repair parts and replacement systems are becoming scarce as more manufacturers leave the business or change their product lines to better meet the industry's demands. This repair and stocking problem is not unique to the C-130, but exists on virtually all aircraft procured before the mid-1970s.

RAMTIP. RAMTIP is a joint U.S. Air Force Systems Command/Air Force Logistics Command program chartered to identify and accelerate the development and insertion of emerging laboratory technologies, with significant R&M payoffs, into Air Force systems. Emerging technology may be loosely defined as any technology ready for transition from a laboratory environment into its first application in an Air Force system. Generally, the technology will require further development before it can be implemented into the targeted system. The technology can be targeted for any Air Force system application (aircraft, missiles, ground support equipment, etc.) at any level within that system (subsystem, component, line replaceable unit (LRU), etc.). The technology must have high payoffs in the R&M area consistent with the U.S. Air Force R&M 2000 goals.

C-130 Electronic Cockpit. Each year, projects are submitted to the RAMTIP office at Wright-Patterson Air Force Base, Ohio, for evaluation and competition for funding. The RAMTIP office evaluates all proposals, makes a tentative ranking, and passes that ranking to a General Officer Steering Group (GOSG) for approval. If selected by the GOSG, the RAMTIP office will fund development of a prototype system for test and evaluation to validate the R&M improvements, and most importantly, to reduce the risk to the implementing command of inserting that technology into production hardware.

In November 1987, HQ MAC submitted a proposal to the RAMTIP office to modify one C-130 with five flat-panel liquid crystal displays (LCD) as a replacement for the analog instruments on the pilot's instrument panel. All the flight director and engine instruments will be displayed on these panels, offering greatly improved reliability, redundancy, and enhanced operations. Figure 1 shows the display configuration. Shown are the pilot and copilot flight and navigation displays, with the engine instrument display located in the center of the panel. A sixth display is located at the navigator's station.

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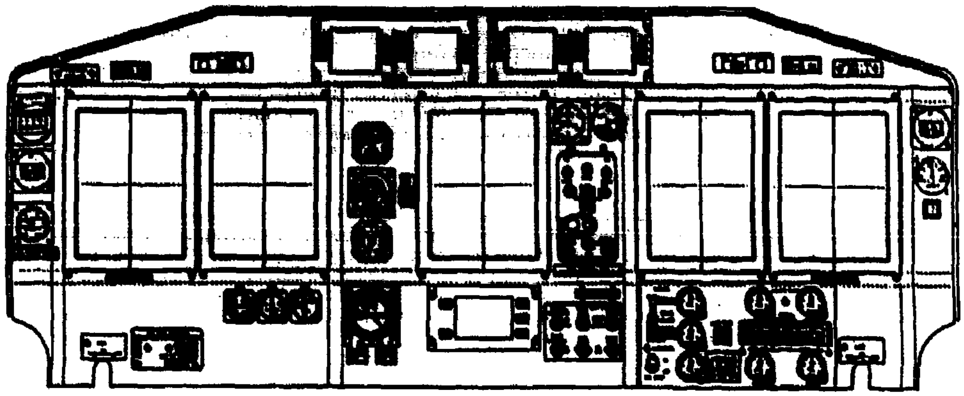

FIGURE 1. DISPLAY CONFIGURATION

Each flat panel display is predicted to have a Mean Time Between Failure (MTBF) of approximately 8,000 hours. The present instruments show about 55 hours Mean Time Between Maintenance, Inherent (MTBMI). The new instrument suite, using the flat-panel displays, can be expected to provide 200-300 hours MTBMI. We use MTBMI as an operational measure of reliability, where MTBF is a prediction based upon piece part reliability, generally demonstrated in a laboratory environment.

In March 1988, the MAC submission was approved by the GOSG. Lockheed Aeronautical Systems Company (Georgia) was awarded the contract in August 1988 by Warner-Robins Air Logistics Center as part of their basic ordering agreement with Lockheed. Lockheed selected Litton Systems Canada Limited as the supplier for the flat-panel liquid crystal display. The Wright Research and Development Center's Cockpit Integration Directorate at Wright-Patterson Air Force Base, Ohio, is providing the technical consultation on the display performance requirements. This four-year effort has a total projected cost of approximately $13 million, with funding provided by the RAMTIP office.

LIQUID CRYSTAL DISPLAYS (LCD).

Technology. The LCD is expected to provide us with the next generation of electronic displays for military aircraft, succeeding the CRT. LCDs operate using the unique characteristics of liquid crystals. The properties of liquid crystals are in between those of a crystalline solid, whose properties vary with direction, and a liquid, whose properties are the same in all directions. The cigar-shaped liquid crystal molecules, known as the twisted nematic crystal, possess the unique property that when a voltage is applied, they unwind and align themselves parallel to the electric field. Using optical polarizing principles, the alignment of the molecules either blocks light or allows light to pass.

Thousands of these molecules are arranged vertically and horizontally as individual dots, called pixels, of liquid crystals in an X-Y matrix pattern on glass. Through application of appropriate software, each of these pixels can be controlled into a "block" or "pass" mode, thus enabling pictures of high detail to be formed on the glass viewing surface. A "backlight" behind the glass makes these images visible to the operator under high ambient light conditions. The LCD principle of operation is depicted in Figure 2.

LCDs are being developed in various sizes. The active display area for the C-130 RAMTIP project is 6.0 x 8.0 inches. The pixel (dot) arrangement is 960 x 1,280 pixels. The electrical signal transmitted from the Display Processor controls a thin film transistor switch at each pixel. By opening and closing these switches via software control, the desired pixels can be illuminated to various levels, and the nonselected pixels remain dark. Four pixels are then grouped into cells where each pixel is aligned with its own primary color filter (red, blue, or green). Multiple colors with variable shading levels can be displayed.

LCD Advantages. Compared to CRTs, LCDs have been described as offering savings of about 60 percent in volume, 70 percent in weight, and 80 percent in power. With increased production capability, LCD costs have been estimated to be 50 percent of the cost of a comparable CRT with 10 times the reliability. The shorter depth of the flat panel LCD is a major advantage in retrofitting this technology to existing aircraft because of the usual lack of space behind the existing instrument panel. The larger depth of the CRT makes it cost-prohibitive in many current aircraft, this being the case with the C-130. To retrofit an existing C-130 with the CRT display would require the entire instrument panel to be moved aft to allow more space behind the panel to accommodate the CRT. This would result in the control column also being moved aft, impacting the flight control system design and significantly increasing the cost of the modification.

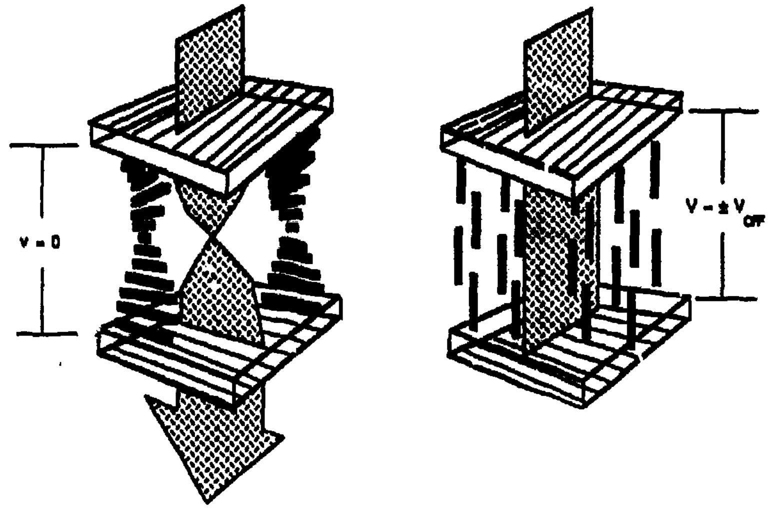

FIGURE 2. LCD PRINCIPLE OF OPERATION
(One Picture Element - Pixel Is Shown)

Another disadvantage of CRTs is the larger the display, the dimmer the image. This is because the electron beam has to scan faster, and therefore, cannot excite the CRT phosphors as well as it can when scanning more slowly, as in a smaller CRT. The shadow mask also absorbs about 80 percent of the incident energy. In LCDs, the brightness of a pixel is independent of the size of the display. Also, no horizontal/vertical linearity or focus adjustments are required in the LCD.

SYSTEM DESCRIPTION.

General. The graphics processing for the various display formats and input signal management is performed by the electronic modules inside the Display Processors. Two Display Processors are used in the system, each of which can support the six displays. A total failure of one Display Processor does not degrade the operation of the system. A design feature of the displays is called "graceful degradation." Instead of catastrophic-type failure, the display quality may become degraded with the failure of individual pixels caused by electrical shorts or switch failures. Individual pixels or lines of the display unit fail, indicated by always-on or always-off dots on the display. Depending upon the location and groupings of the pixels, the display may be quite useable and replacement of the display unit deferred. Minimal standby flight instruments and a Standby Engine Instrument Display are provided as safety-of-flight backup capability if the complete primary display system were to fail.

System Architecture. The system architecture is centered around the Electronic Flight Instrument System (EFIS) MIL-STD-1553B data bus, with analog and ARINC 429 serial interfaces used for redundancy and for minimum impact on the existing systems. The system architecure/inter-face is depicted in Figure 3.

To provide the enhanced navigation displays in the map format, an interface to the Self-Contained Navigation System (SCNS) MIL-STD-1553B data bus is used to transfer navigation data to the display system. The SCNS software was modified to increase the data rate for critical display data from 5 hertz (HZ) to 20 HZ. The two Display Processors are remote terminals on the SCNS data bus enabling the SCNS to provide the data required for the navigation displays. The SCNS analog interface is retained to support the autopilot and flight director operation.

The Data Acquisition Units (DAU) contain the signal conditioning circuitry which interfaces with the engine sensors to format the data for display of engine operating information. The signals are converted to digital form and transmitted over the EFIS data bus to the Display Processors for presentation on the display units. The DAUs are arranged to provide operational redundancy via an ARINC 429 interface to the Standby Engine Instrument Display. This provides a backup capability in the event of a complete failure of the EFIS data bus. The Standby Engine Instrument Display is a monochrome LCD located in the lower center of the instrument panel. It provides an alpha-numeric presentation of engine data as a backup to the primary display system.

Two Air Data Computers (ADC) provide information to the Display Processors via the EFIS data bus, with also a direct interface to the Display Processors provided by dedicated ARINC 429 serial data buses. The Identification, Friend or Foe (IFF) is connected to ADC No. 1 for encoded altitude information.

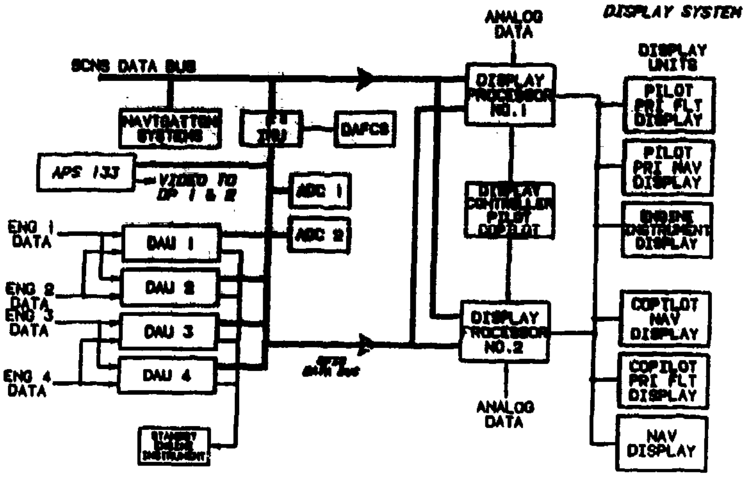

FIGURE 3. SYSTEM ARCHITECTURE

The Inertial Navigation Unit (INU) is controlled by the SCNS over the SCNS data bus. The Display Controllers are monochrome LCDs and are connected to the Display Processors via an ARINC 429 high speed, serial data bus. The Display Controllers are centered on the upper portion of the instrument panel and provide the pilot and copilot with menus that enable display format selection and switching.

The APS-133 Type II Radar is interfaced to the display system using a Radar Interface Unit. This interface unit is a modified C-17 unit providing dual independent video outputs to the Display Processors. The independent outputs provide the capability for two different radar ranges to be displayed simultaneously, but the radar cannot operate in two different modes simultaneously. One of the outputs is shared by the pilot and copilot and the second output is used by the navigator. A failure of a Display Processor will cause the system to revert to a common radar range selection for the pilots and navigator. The Radar Interface Unit is connected to the EFIS data bus for receipt of attitude and heading stabilization signals and for range control. The radar mode control functions are performed with dedicated control panels.

The Display Controllers are connected to the Display Processors via ARINC 429 data buses. The Display Controllers provide the capability to control which information is displayed on the display units. Two Display Controllers are installed on the instrument panel, one each for the pilot and copilot. Controls for the display unit at the navigator's station will also be provided. The pilot and copilot will each exercise control over the configuration of his respective display units. However, in the event of a failure of a pilot's/copilot's Display Controller, the other pilot will have the ability, using his own Display Controller, to control the configuration of the other pilot's display unit.

The Standby Engine Instrument Display is a monochrome LCD located in the lower center of the instrument panel. It provides a numerical presentation of engine data as backup to the primary display system. It is connected to the four DAUs via ARINC 429 data buses to receive engine data directly.

The Digital Automatic Flight Control System (DAFCS) is a new autopilot/flight director system for the C-130 that replaces the old E-4 Autopilot and CPU-65 Flight Director. There are no connections between the autopilot and the MIL-STD-1553B data buses. All of the interfaces use discrete wiring. To support all of the analog interfaces for the autopilot and flight director, the present navigation instrument switching system is retained, but only a few of the interfaces are used by the display system.

<u>Displays</u>. The two primary flight displays are the outboard displays located directly in front of the pilots. The information previously displayed on the pilot's/copilot's attitude direction indicator (ADI), airspeed indicator (ASI), vertical speed indicator (VSI), altimeter and partial (horizontal situation indicator (HSI) is now displayed on the primary flight display. Flight director mode data and some navigation data are also presented on this display. There is only one format available, but a declutter capability is included in the design.

The two navigation displays are located inboard of the primary flight displays on the main instrument panel. The navigation display has a basic map format with minor variations to suit the navigation mode selected. Data previously displayed on the HSI and two bearing distance heading indicators (BDHI) is presented on this display. Radar is displayed as an overlay on the map display for the pilot and copilot. One BDHI is retained on the main instrument panel to provide backup navigation information in case of complete loss of display system functions.

The center display is used primarily to monitor engine parameters with limited caution and warning information displayed on the bottom of the display. The Standby Engine Instrument Display is used to display essential engine data upon the complete loss of the display system functions.

The additional display at the navigator's station has a basic map format similar to that available to the pilot's and copilot's navigation displays. Radar is displayed as an overlay on the map display, or as a radar-only display without any computer-generated symbology. All of the navigator's present instruments are retained. The display unit replaces only the navigator's radar display. Independent control of radar range is provided for the navigator's display unit.

Various display formats and symbology were reviewed by a working group consisting of MAC and Lockheed representatives from several functional areas, including aircrew standardization and evaluation, aircrew training, flight safety, logistics, human factors engineering, software development, and crew station design. Each display format will be evaluated in detail during systems integration and flight testing.

Hardware Redundancy. Two Display Processors are used to formulate the information for the six displays. Six unique displays, with full function capability, can be supported after the complete failure of one of the Display Processors. Following the loss of the capability from Display Processor No. 1, the bus controller functions for the EFIS bus are performed by Display Processor No. 2. Although complete operation of the system can be performed by one of the Display Processors, the pilot-controlled operations are normally performed by Display Processor No. 1 and the copilot functions by Display Processor No. 2 No flight-crew action is required following the failure of a Display Processor; however, an advisory message is displayed to notify the crew of the loss of one level of redundancy.

Following a failure of one of the display units, the pilot/copilot may reallocate the functions of the remaining serviceable units to provide information displays adequate for the completion of the mission. The most critical display units are the pilot's flight display, copilot's flight display, and the engine instrument display. If one of these fails, the appropriate information is transferred to either the pilot's or copilot's navigation display. The transfer is accomplished manually from either of the two Display Controllers.

The four DAUs are arranged to provide redundancy of interface and handling of engine data. The two primary DAUs each process data from two engines. Each primary DAU is backed up by a secondary DAU processing the same data. The same data transferred across the EFIS bus is also transmitted on ARINC 429 buses to the Standby Engine Instrument Display to provide a back-up capability in the event of a complete failure of the EFIS data bus.

Display Control. The two Display Controllers are mounted in the upper center of the instrument panel. Each contains two simpler, monochrome LCDs with a 3.3 x 2.3 inch usable area with eight pushbuttons associated with each half of the Display Controller. The selections are menu-driven with the functions of the pushbuttons changing as selections are made. Communications and navigation radio frequencies with channel numbers are displayed at the bottom of the Display Controllers. These frequencies are readouts only, with no control of the radios provided from these panels.

Selections which control discretes from the Display Controllers can only be made from that particular Display Controller; i.e., pilot controls pilot functions and the copilot controls the copilot functions. Some redundancy is built into the Display Controllers, but full functionality cannot be maintained after complete failure of a Display Controller. Flight director mode selection cannot be made for the side associated with the failed unit, but limited raw data display selection is still available.

PROJECT SCHEDULE. The project is broken down into four distinct phases corresponding to the applicable fiscal year that the effort is funded. The major tasks associated with each phase are summarized below:

Phase I (FY 88) - Begin Detailed System Design.
- Select Equipment Suppliers.
- Complete Interface Design Documents.

Phase II (FY 89) - Complete System Design.
- Begin Integration Testing.
- Fabricate Installation Components.

Phase III (FY 90) - Modify Aircraft.
- Conduct Engineering Flight Test.
- Prepare and Deliver Aircraft to MAC.

Phase IV (FY 91) - Support MAC Operational Test and Evaluation.
- Demodify Aircraft.

OPERATIONAL TEST AND EVALUATION (OT&E). Following the modification of the C-130 at Lockheed's facility in Georgia and the initial engineering checkout and flight test, the aircraft will return to the 314 Tactical Airlift Wing at Little Rock Air Force Base, Arkansas. The C-130 will be flown and maintained by MAC operations and maintenance personnel during a six-month OT&E period. The USAF Airlift Center (ALCENT) located at Pope Air Force Base, North Carolina, will direct the testing and complete the final test report.

The OT&E will evaluate the operational effectiveness and suitability of the LCD technology in the aircraft installation. Major operational effectiveness issues to be evaluated include:

- Sunlight Readability.
- Readability From Multiple Wide Viewing Angles.
- Information Clutter and Dynamics.
- Ease of Use of the Display Controllers.
- Display Formats and Symbology.
- Night Vision Goggle Compatibility.

Operational suitability issues will address supportability of the technology and include the following:

- System Reliability and Maintainability.
- Maintenance Skill Level Required to Maintain and Support.
- Fault Detection and Isolation.
- Support Equipment Requirements.

CONCLUSION. The use of liquid crystal flat panel displays has the potential to revolutionize the display of critical flight and performance monitoring information. Improved reliability, maintainability, and operational effectiveness will drive the use of flat panel LCDs in the design of our next generation of aircraft, as well as the modernization/modification of current aircraft cockpit displays.

This technology supports MAC's and Warner-Robins Air Logistics Center's efforts to modernize C-130 and C-141 flight stations. This RAMTIP project will demonstrate the benefits and identify the problems with this technology, greatly reducing the risk of successfully integrating flat panel LCDs in the C-130 and C-141 aircraft.

DISCLAIMER

This research report represents the views of the author and does not necessarily reflect the official views of the Department of Defense or the United States Air Force.

BIBLIOGRAPHY

1. "C-130 Electronic Cockpit RAMTIP Project Plan, #8726," HQ MAC/LGR, Scott Air Force Base, Illinois, 20 November 1987.

2. Bruce D. Nordwall, "Navy Chooses LCD Technology For New A-12 Color Displays," Aviation Week and Space Technology, 4 September 1989.

3. Peter Sadler, Lockheed Aeronautical Systems Company - Georgia, "General Systems Description, C-130 Electronic Cockpit," 10 January 1989.

4. Statement of Operational Need (SON) for Enhanced Theater Airlift, MAC 001-89, HQ MAC/XR, Scott AFB, Illinois 62225-5001.

APPORT DES TECHNOLOGIES NOUVELLES DANS LA CONCEPTION DU POSTE DE PILOTAGE D'UN FUTUR AVION DE TRANSPORT MILITAIRE

par

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I. - EXPERIENCE AEROSPATIALE DANS LE DOMAINE DES AVIONS DE LIGNE DE TYPE AIRBUS

I.1 - Généralités

Le cockpit est l'endroit de l'avion vers lequel tous les systèmes convergent pour dialoguer avec le pilote.

Dans les 10 dernières années, de grandes étapes ont été franchies en ce qui concerne l'ergonomie et les technologies, qui ont conduit à des modifications profondes dans la philosophie de conception du cockpit, pour mieux tenir compte des exigences actuelles d'exploitation et de sécurité. L'AEROSPATIALE, qui a actuellement la responsabilité de la conception et du développement des postes A330, A340 et HERMES, possède une large expérience du sujet, après avoir défini tous les postes de la famille AIRBUS mais également de la famille ATR.

La définition d'un cockpit est le résultat d'un processus complexe, qui met en cause :

- l'expérience acquise sur les programmes précédents,
- les résultats des efforts de recherche,
- les informations provenant de différents interlocuteurs (compagnies aériennes, pilotes, autorités de certification, fabricants de systèmes...),
- la méthodologie propre à l'AEROSPATIALE, basée sur une analyse statique et une phase de développement pour la conception et sur une analyse dynamique pour la validation.

* L'analyse statique repose sur des critères tels que :
  - la visibilité externe
  - la visibilité interne
  - le confort (espace libre autour de la tête, ...)
  - l'accès au poste de travail.
  - diverses règles ergonomiques

  Cette phase utilise largement les moyens informatiques (CAO) et aboutit à la fabrication de maquettes d'installation.

* La phase dite de développement est la phase pendant laquelle la plupart des concepts et des solutions relatives à l'interface Homme-Machine sont proposés, essayés et adoptés, en s'appuyant sur divers moyens informatiques et des simulateurs spécifiques au programme concerné.

* L'analyse dynamique consiste en la validation a posteriori du processus lors d'une campagne d'essais en vol : la tâche pilote est évaluée au travers d'une analyse globale de sa charge de travail. A partir de mesures de paramètres internes (variabilité cardiaque par exemple) et externes (incidence avion, plan de vol...), un modèle a été construit , qui permet de restituer le niveau de la charge de travail et d'en déterminer les limites acceptables.

I.2 - La solution AIRBUS A 300 et A 310 FFCC

Le concept FFCC (Forward Facing Crew Cockpit) est basé sur le fait que l'équipage (à 2 ou à 3) regarde vers l'avant.

Ceci est une conséquence directe de l'introduction dans ces avions de la technologie digitale, qui a permis une complète réorganisation du panneau plafond et du panneau latéral.

Les commandes des systèmes sont situées sur le panneau plafond. Une amélioration importante de l'exploitation opérationnelle est apportée par la philosophie "poste éteint" : lorsque tout va bien, tous les boutons poussoirs sont éteints. La préparation du poste en est grandement facilitée. Cette philosophie est combinée à une utilisation cohérente d'un code de couleurs. Les boutons poussoirs lumineux sont intégrés dans les synoptiques systèmes, indiquant soit une continuité, soit une interruption du circuit concerné.

Le panneau latéral a été énormément réduit : il n'est plus utilisé à titre opérationnel et est maintenant réservé uniquement à la maintenance.

Conçu dès le départ pour un équipage à 2, l'A 310 est devenu un programme clé dans le domaine des cockpits d'avions civils, du fait d'autres améliorations majeures liées aux technologies digitales : l'installation de 6 tubes cathodiques pour la présentation d'informations sur la planche de bord, et l'introduction d'un calculateur dédié à la gestion du vol. Ces deux nouveautés ont vu leurs fonctions accrues sur l'A320 et sont présentées plus en détail dans la section suivante.

Le poste de l'A310 peut en fait être considéré comme un poste de transition, combinant à la fois l'utilisation d'instruments conventionnels et celle de technologies nouvelles (comme les tubes cathodiques). Celles-ci ont été étendues et ont atteint leur aboutissement avec le poste de pilotage de l'AIRBUS A320.

I.3 - De l'A 320 à l'A330-340

Le cockpit de l'AIRBUS A 320 constitue un important pas en avant, comparé à tous les autres cockpits modernes, et est maintenant considéré comme le standard mondial en matière de postes de pilotage. La meilleure preuve en est le fait que le Boeing B747-400 et le Mac Donnell-Douglas MD11 ont été conçus sur la base de la même architecture générale. Bien entendu, les principales caractéristiques qui font le succès de l'A320 ont été reconduites sur les AIRBUS A 340 et A330, c'est à dire principalement :

- l'introduction de commandes de vol électriques avec des manches latéraux et une commande de poussée miniaturisés.

- la généralisation de tubes cathodiques pour la présentation de toutes les informations primaires (l'A 320 est ainsi le premier poste à matérialiser le concept "All Glass Cockpit").

1 - 3 - 1 - Les Instruments

Les Commandes de Vol Electriques (CDVE), entraînant l'utilisation de manches latéraux, ont permis une réorganisation optimale de la planche de bord, avec pour chaque pilote une meilleure visibilité sur les deux tubes devant lui et sur les deux tubes de la planche centrale.

De l'A 310 à l'A 340, une série de règles de base concernant la symbologie sur tubes cathodiques a été définie et améliorée par l'effort conjugué de pilotes et d'ingénieurs.

On peut en signaler ici les principales :

- lors de chaque phase de vol, seules les données optimales sont présentées ; ainsi des informations utiles pour d'autres phases de vol que la phase en cours ne sont pas montrées et ne viennent pas surcharger inutilement les écrans.

- aucune charge de travail supplémentaire n'est demandée à l'équipage pour commander et comprendre les informations présentées.

- aucun entraînement spécifique ni changement important dans les processus mentaux ne sont nécessaires pour utiliser les CRT.

<u>Le système EFIS</u>

Les quatre tubes cathodiques des deux planches pilotes constituent l'EFIS (Electronic Flight Instrument System).

Devant chaque pilote se trouve le "Primary Flight Display" (PFD) qui donne toutes les informations nécessaires au pilotage à court terme de l'avion.

Leur plus grande taille (7.25" x 7.25") comparée aux tubes de l'A 310 (6.25" x 6.25") permet de présenter un T-basique complet :

- Attitudes au centre de l'image
- Anémométrie sur la gauche
- Altimétrie et variomètre à droite
- Cap dans la partie inférieure.

La partie supérieure donne des informations sur les modes du pilote automatique actifs ou armés.

Sur le même niveau horizontal se trouve le "Navigation Display" (ND), réservé à la gestion du vol à long terme. On y présente la situation de l'avion par rapport à son plan de vol. Le pilote peut sélectionner plusieurs modes, en fonction de la situation :

- le mode ARC, où l'on montre le plan de vol avec l'avion au bas de l'écran
- le mode ROSE MAP, avec le plan de vol, et l'avion au centre de l'image
- les modes ROSE VOR et ROSE ILS (identiques au HSI mécanique).

Pour les deux premiers modes, le pilote peut choisir 6 échelles de cartes, allant de 10 à 320 NM (fonction "zoom").

Les informations du radar météo, des options supplémentaires (aides radio, points tournants, aéroports) ou les positions d'autres avions peuvent être superposées à ces images, avec les positions et/ou tailles adéquates correspondant à l'échelle et au mode sélectés.

Pour la sélection des fonctions EFIS, chaque pilote dispose d'un boîtier de commande installé sur l'auvent.

Le système ECAM

Les deux tubes cathodiques, situés sur la partie centrale de la planche de bord, constituent l'Electronic Centralized Aircraft Monitoring (ECAM).
L'écran du haut est l'"Engine and Warning Display" (EWD). Il montre, en partie supérieure :

- les paramètres primaires des moteurs
- la position des becs et des volets
- le carburant total

La partie inférieure de l'écran EWD présente :

- en utilisation normale, la page "MEMO" qui donne des informations sur les systèmes actifs temporairement tels que l'APU, le dégivrage, les messages cabines (NO SMOKING/SEAT BELTS),...

- en cas de panne, les messages d'alerte ou d'alarme et les procédures associées.

L'écran inférieur est le "System Display" (SD) qui présente :

- les synoptiques des systèmes avion, qui peuvent soit être appelés manuellement par le pilote, soit être présentés automatiquement (on montre le système le plus pertinent compte tenu de la phase de vol en fonctionnement normal, ou le synoptique du système en cause en cas de panne). Pour l'A330 et l'A340, 13 pages systèmes ont été définies: MOTEURS (paramètres secondaires), PRELEVEMENT D'AIR, PRESSION CABINE, ELEC. ALTERNATIF, ELEC. CONTINU, HYDRAULIQUE, APU, CONDITIONNEMENT D'AIR, PORTES, ROUES, COMMANDE DU VOL, CARBURANT, CIRCUIT BREAKERS et CROISIERE.

- une page STATUS contenant des informations sur l'état opérationnel réel de l'avion et sur d'éventuelles limitations opérationnelles après panne.

Un boîtier de commande ECAM est situé sur le pylône central, pour la sélection manuelle des pages du "System Display".

Il existe aussi des dispositifs permettant d'attirer l'attention des pilotes en cas d'alarme : des boutons lumineux sur l'auvent, combinés à des alarmes sonores, demandent à l'équipage de se référer à l'écran EWD où un message est apparu.

Le système ECAM bénéficie au maximum des possibilités de reconfiguration offertes par la technologie digitale et les écrans de visualisation électroniques.

Il améliore le confort de pilotage en minimisant la charge de travail, permettant ainsi à l'équipage de se consacrer à des tâches de synthèse comme la gestion optimale de la mission et de la machine.

Des reconfigurations, manuelles par action pilote ou automatiques, sont possibles afin de garder toutes les informations disponibles en cas de panne d'une unité de visualisation.

1 - 3 - 2 - Les Commandes de vol

Une conséquence première de la généralisation des CDVE est l'utilisation de manches latéraux.

Les modifications de trajectoire avion sont envoyées aux calculateurs qui commandent les organes de puissance des surfaces mobiles. Ainsi, des actions musculaires importantes ne sont plus nécessaires pour transmettre ces informations.

En fonctionnement avec Pilote Automatique, les manches latéraux restent en position neutre ; le pilote peut à tout moment reprendre le contrôle par action sur le manche, désengageant ainsi le PA.

Les manches latéraux offrent l'avantage d'un meilleur confort de pilotage (vision sans obstacle du pilote sur les instruments et accès plus aisé au siège) et d'une importante réduction de poids.

Allant de pair avec l'introduction du manche latéral, des manettes des gaz miniaturisées ont également été adoptées, profitant pleinement du concept "Full Authority Digital Engine Control" (FADEC).

Ici aussi, les transmissions mécaniques ont disparu, entraînant une réduction de la taille des manettes.

Des positions fixes permettent la sélection aisée des modes de poussée limite. Lorsque l'automanette est active, il n'y a pas de mouvement de la manette.

1 - 3 - 3 - La Conduite automatique du vol

L'introduction de calculateurs numériques sur A 310 a entraîné des évolutions importantes dans les systèmes de conduite automatique du vol, aussi bien du point de vue matériel (en terme d'intégration de systèmes) que du point de vue logiciel. Cela a simplifié énormément l'interface Homme-Machine : accès à des modes supérieurs, couplage entre commandes automatiques de tangage et de poussée.

L'A310 fut aussi le premier programme à être équipé d'un "Flight Management System" (FMS), Calculateur de Gestion du Vol.

Les fonctions et l'autorité de ce système ont été augmentées sur les programmes suivants, en même temps qu'il a vu son intégration progressive avec les autres systèmes de conduite de vol, ce qui a conduit pour l'A 330/340 au "Flight Management Guidance and Envelope System" (FMGEC).

Les deux FMGEC de l'A330/A340, associés à un "Flight Control Unit" (FCU) et à deux "Multipurpose Control and Display Units" (MCDU) pour l'interface pilote, constituent le système de Conduite Automatique du Vol.

Ce système offre :

- la fonction gestion du vol, qui permet une navigation complète (horizontale et verticale simultanément).
- des fonctions de guidage : pilote automatique, directeur de vol et contrôle automatique de la poussée.

- la fonction "Enveloppe de Vol" : enveloppe de vitesses, détection du cisaillement de vent et de l'"alpha-floor".

Grâce à l'utilisation d'une importante base de données de navigation, comprenant les aides radio, les points tournants, les routes aériennes, les aéroports, les procédures de départ et d'arrivée, la fonction Gestion du Vol permet à l'équipage de construire le plan de vol adéquat, et de le modifier facilement à tout moment du vol par l'intermédiaire de la MCDU. Le pilote peut surveiller en permanence la situation horizontale par la présentation du plan de vol sur la "Navigation Display". Dans le plan vertical, le système calcule les profils de montée et descente, ainsi que les vitesses et altitudes de croisière, de façon à minimiser le coût ou la consommation de carburant. Pour cela, le système tient à jour le Plan de Vol, quelle que soit la manière dont le pilote l'a défini (route compagnie, "city-pair", point tournant par point tournant) et modifié ("direct TO", procédures d'attente,...), détermine la position avion et sa distance au Plan de Vol, et réalise un guidage automatique le long de ce plan de vol.

Il réalise aussi des prédictions de temps, de carburant et d'altitude à chaque point tournant en utilisant les modèles aérodynamiques et moteurs de l'avion, les conditions de vol actuelles et celles prévues, et l'indice de coût de la compagnie.

Le dialogue entre les pilotes et les FMS se fait par l'intermédiaire de deux boîtiers de commande et de visualisation (MCDU) à écran couleur, particulièrement faciles à utiliser malgré la complexité et la variété des possibilités du système.

De même que le système ECAM, le système de conduite automatique du vol a profondément modifié la charge de travail de l'équipage, du fait que le couplage entre système de guidage et système de gestion du vol permet désormais un guidage automatique complet le long d'un plan de vol à 3 dimensions, du décollage à l'atterrissage.

1 - 3 - 4 - La Maintenance

Sur l'A310, le panneau latéral a été extrêmement réduit, et réservé à des fins de maintenance. A partir de l'A320, il a totalement disparu, et a été remplacé par le Calculateur Central de Maintenance (CMC).

Les fonctions BITE (Built In Test Equipment) ont été intégrées dans les calculateurs, et grâce à ce calculateur central de maintenance, peuvent désormais être commandées et présentées via la MCDU ; il n'y a donc plus qu'une interface unique entre les pilotes, la maintenance au sol et les systèmes. Les informations, en anglais clair, concernant chaque panne apparue, y sont disponibles pour les spécialistes de maintenance : ils peuvent connaître l'heure de la panne, le chapitre ATA correspondant, le LRU concerné, et ont également accès aux calculateurs connectés à partir d'un seul point de l'avion.

1 - 3 - 5 - La Bibliothèque Electronique

Le Système Bibliothèque Electronique Embarqué (ELS: Electronic Library System) permet la consultation des divers documents ou informations nécessaires à l'exploitation de l'avion, embarqués dans une unité de stockage électronique.
Ce systeme est actuellement à l'étude à l'AEROSPATIALE pour l'A330 et l'A340.

Grâce aux technologies utilisées, l'ELS permet de disposer à bord d'informations exhaustives et cohérentes et d'en assurer une mise à jour plus aisée qu'avec une documentation papier.

Chaque pilote dispose d'un écran plat à haute résolution permettant la recherche et l'affichage, pendant toutes les phases du vol, des informations textuelles et graphiques, aujourd'hui éditées sur support papier.

Les manuels de vol (FCOM), les diverses procédures, la M.E.L ainsi que les cartes d'approche et de terrain sont accessibles à partir de chaque poste et peuvent être édités à la demande sur l'imprimante installée dans le pylône.

La recherche d'information est facilitée par l'utilisation de divers modes d'accès (menus, désignation, recherche de mot, ATA, ...).

De plus, une présélection dynamique d'information est proposée à l'utilisateur en fonction des situations de vol ou d'un évènement cockpit (alarme ECAM).

Les informations destinées au pilote sont complétées par les informations de maintenance permettant de disposer en ligne de l'ensemble des diverses données spécifiques à l'avion.

Des terminaux situés dans les zones de maintenance assurent aux équipes sol le support nécessaire aux interventions, grâce à l'accessibilité aux documents de maintenance.

I.4 Futur et perspectives pour les avions civils

Les programmes lancés dans la seconde moitié des années 90 bénéficieront d'une nouvelle révolution dans l'avionique : le concept de tolérance aux pannes, l'avionique modulaire intégrée, un nouveau standard de bus (ARINC 629), l'avion tout-électrique, la transmission de données optiques, sont les nouveaux principes que l'on envisage d'appliquer à ce moment là.

L'Interface Homme-Machine bénéfiera elle aussi de l'introduction de technologies nouvelles, telles que les écrans plats à cristaux liquides, de nouveaux systèmes de désignation, la Commande Vocale, des organes de commande à mini-déplacements, ...

L'AEROSPATIALE poursuit son effort de recherche, regardant déjà au delà de l'A 340, l'A 330 et l'A 321. Le simulateur de vol prospectif EPOPEE est utilisé pour évaluer ces nouvelles technologies :

- des visualisations 3D permettront de superposer des symbologies de pilotage à une image du sol, et contribueront à un pilotage instinctif de l'avion, par exemple lors d'approches IFR, profitant ainsi des nouveaux systèmes de navigation tels que MLS (Microware Landing System) et GPS (Global Positionning System).

- un système de bibliothèque électronique, totalement intégré aux autres systèmes avioniques et au cockpit (pour la saisie de données et la visualisation) conduira à un cockpit "sans papier", et contribuera encore à simplifier la charge de travail du pilote.

- dans le futur, l'avion ne sera plus considéré comme un élément isolé dans l'espace aérien, mais sera relié à un important réseau de communications et d'échanges de données.

La coopération active entre sol et bord est la clé de l'efficacité du système global. Pour cela, de nouveaux systèmes sont à l'étude, qui ont un impact sur l'interface homme-machine à bord de l'avion:

- le MLS (Microwave Landing System)
- le TCAS (Traffic Alert and Collision Avoidance System)
- l'ACARS (ARINC Communication Adressing and Reporting System) pour les communications air/sol de la compagnie
- la liaison de données ATC Mode S qui améliorera de façon significative le dialogue entre le Système de Contrôle Aérien et l'avion. Cela devrait améliorer la régulation du trafic, et donc amener des gains significatifs en efficacité, sécurité, performances, économie de carburant,...)
- les communications par satellites (SATCOM).

II. - EXPERIENCE ACQUISE DANS LE DOMAINE DU TRANSPORT AERIEN MILITAIRE

Au cours des années 1980 l'Aérospatiale a conçu et réalisé des porteurs spéciaux à partir des C 160 de série, puis elle a mené à l'étude de la rénovation de l'avionique et de la flotte des C 160 du COTAM. Cette analyse conduite en accord avec les Services Officiels français a abouti au développement et la mise au point d'un nouveau concept de conduite de la mission de transport aérien.

II.1 - Le besoin exprimé par le COTAM

Il s'agit de fournir aux C 160 les moyens de leur mission dans le nouveau contexte géopolitique envisagé :

- Le nouveau système de localisation doit être précis, autonome et discret.

- L'ergonomie d'installation doit proposer au pilote une assistance pour les opérations tactiques de suivi de terrain, de largage et de poser sur les terrains sommaires.

- L'avionique nouvelle doit être compatible avec la durée de vie estimée de l'avion (2010).

- Le nouveau concept doit être implanté sans modification majeure de l'avion.

II . 2 - Identification du besoin par l'Aérospatiale, Département Avion Militaire

Le besoin d'avionique militaire sur l'avion de transport militaire peut être résumé en plusieurs points caractéristiques.

A - Effectuer une localisation discrète autonome à l'aide de au moins trois sources indépendantes et précises ; garantir une précision de localisation en mode nominal et en mode dégradé (une source invalide).

B - Gérer les performances de l'avion et la navigation au sens large : il faudra tenir compte des surfaces hostiles définies par les menaces adverses, il faudra gérer des horaires précis, il faudra optimiser les capacités de charges offertes de l'avion sur des terrains sommairement aménagés.

C - Assurer l'autoprotection passive et active de l'avion au cours de ses déplacements : écoute discrète des systèmes d'interception, alarme de l'équipage, réaction aux menaces directes.

D - Fournir à l'équipage les informations relatives à son plan de mission (Navigation, livraison, communication) sur des surfaces
- dédiées au pilotage direct (visu tête haute)
- dédiées à la navigation (écran tête basse)
- de communication (écran tête basse).

E - Aider l'équipage à conduire la machine en automatisant les tâches de routine telles que surveillance des paramètres de contrôle des systèmes, telles que tenue de paramètres de pilotage donnés, telles que séquences de vol à profil prédéfini.

F - Assurer tous les calculs à caractère tactique : suivi de l'itinéraire et des horaires, guidage pour largage, guidage pour poser, limitations adaptées.

G - Permettre sans intrusion adverse l'ensemble des liaisons opérationnelles entre l'avion et le centre de contrôle des missions : transmissions cryptées de données tactiques permettant de remettre à hauteur la situation de menace et l'itinéraire, transmissions cryptées relatives à l'avancement de la mission.

II.3 - Les contraintes d'aménagement à bord

Ces contraintes sont d'ordre mécanique, d'ordre électrique, d'ordre ergonomique.

- Il n'a pas été envisagé, pour des raisons évidentes de coût, de redéfinir un nouveau poste de pilotage ; il a été décidé de rechercher les technologies autorisant l'installation des interfaces de pilotage et de commande nécessitées par le besoin défini, dans l'environnement mécanique du C 160.

- Il n'a pas été envisagé d'étude ni de définition de systèmes nouveaux, mais l'extrapolation d'équipements existants et connus. Dans ces conditions, les liaisons électriques sont analogiques, discrètes ou numériques, et permettront une intégration aisée sur C 160.

- Les dimensions mécaniques des interfaces sont compatibles avec les panneaux d'implantation ; le besoin d'éclairage de nuit avec port des lunettes de vision nocturne a conduit à redéfinir les sources lumineuses. Enfin les temps d'apprentissage de l'avion par un jeune pilote ne sont pas supérieurs à ce qu'ils étaient auparavant.

II.4 - Le concept avionique retenu

4 - 1 - L'architecture

L'architecture est articulée autour d'un calculateur central, doublé par sécurité.

A - Ce calculateur reçoit des informations :

- Initialisations automatiques ou manuelles assurées par l'équipage.

- Données permanentes stockées dans une data base.

- Localisations opérées par des sources indépendantes.

- Mesures avions : anémobarométrie, radio altimètres, débits carburant.

B - Ce calculateur élabore une localisation optimale et un guidage de navigation ; guidage à caractère général conforme aux règles de l'aviation civile ou guidage à caractère tactique pour les missions spécifiques militaires.

C - Ce calculateur distribue les informations

- vers les visualisations tête haute (HUD)
- vers les visualisations tête basse (EFIS, CDU)
- vers le pilote automatique et le directeur de vol
- vers les moyens de radio-navigation et de radio communication.

4 - 2 - Opérations affectées à l'avionique nouvelle

La majorité des calculs sont réalisés dans les deux unités centrales de traitement :

- calcul des performances de l'avion
- calcul des paramètres de vol logistique ou tactique conformément aux profils de vol définis pour la mission
- élaboration des consignes de pilotage permettant de respecter le plan de mission
- gestion automatique de la navigation et des horaires
- gestion automatique (ou manuelle au choix) des moyens de radionavigation et de radiocommunication.

4 - 3 - Les technologies nouvelles pour un avion de transport militaire sont constituées par :

- La gestion centralisée de la mission à l'aide de calculateurs de haute puissance et de grande rapidité, et de lignes numériques de type ARINC 429 100 kilo

- Les interfaces de commande et visualisation fondées sur des écrans plats à cristaux liquides

- L'implantation d'EFIS aux derniers standards technologiques

- Le pilotage de base fondé sur des informations figurées en tête haute au travers d'un HUD : vols à très basse altitude, largages, posers, décollages.

- L'intégration au poste de pilotage de l'ensemble autoprotection

- La compatibilité du poste à l'emploi des lunettes de vision nocturne

4 - 4 - Les nouvelles missions envisagées permettant d'étendre le champ opérationnel des C 160

L'équipage pourra immédiatement être réduit à 3 (2 pilotes + 1 mécanicien navigant). Le quatrième homme en place navigateur sera un renfort pour les missions délicates ou de longue durée.

La sécurité du vol et la sûreté de la mission seront fortement renforcés grâce aux automatismes libérant l'équipage des opérations de routine et grâce à la confortation par le HUD des évaluations visuelles du pilote, et grâce à la grande fiabilité des équipements mis en place.

Une meilleure optimisation des vols sera garantie par la précision nouvelle des moyens de gestion de la mission : gain sur les carburants consommés, gain sur les charges offertes.

Les vols à caractère tactique pourront généralement s'affranchir des conditions de visibilité horizontale et des conditions nuit/jour. Les minima d'approche autonome pourront être considérablement réduits, un objectif initial est d'autoriser l'approche jusqu'au "jaune ROMEO" lorsque les conditions de localisation s'avèrent satisfaisantes. Les largages pourront être exécutés sans visibilité lorsque les conditions de localisation s'avèreront satisfaisantes.

Enfin une surveillance permanente par autotest interne permettra de signaler et de prendre en compte immédiatement et automatiquement toute défaillance de l'un des équipements constitutif du système.

4 - 5 - Le développement financier

La combinaison des ressources limitées du ministère de la défense et des besoins opérationnels à résoudre a conduit à retenir une solution économique mais ambitieuse : l'utilisation des développements les plus récents de l'avionique civile et leur adaptation aux besoins militaires a permis de réduire sensiblement les coûts et les risques comparativement à une solution basée sur une innovation totale dont la durée de mise au point se serait considérablement accrue.

La contrainte financière sera donc sans impact direct sur l'efficacité recherchée du système avionique nouveau.

III - APPLICATIONS ENVISAGEES SUR LES FUTURS AVIONS DE TRANSPORT MILITAIRE

III - 1 - MOYENS MATERIELS permettant de concevoir un nouveau poste de conduite de cargo militaire

1 - 1 - Le pilotage à court terme

Seul un pilotage tête haute permet de résoudre l'ensemble des besoins d'information et de guidage.
En particulier les phases délicates de vol à vue : manoeuvres de poser et décollage sur terrains sommaires, manoeuvres de largage avec et sans la vue du sol, manoeuvres de largage à très faible hauteur, suivi d'un itinéraire à très basse altitude ne peuvent être conduites avec efficacité, sûreté, sécurité que si le pilote assure simultanément le contrôle des paramètres de pilotage et la surveillance du monde extérieur.

Une analyse de champ visuel démontre qu'un confort courant de pilotage serait atteint pour une couverture transversale de 30° et verticale de 20° au moins.
Des têtes optiques de type holographique et de type couleur doivent être envisagées, elle sont en cours de développement.

1 - 2 - La navigation à moyen et long terme

Les figurations de navigation en altitude actuellement exploitées sur les aéronefs commerciaux sont immédiatement utilisables dans les mêmes conditions.
Elles ne permettent cependant pas d'assurer la fonction suivi de terrain dès que l'on s'écarte de l'itinéraire programmé.

Les systèmes de numérisation de terrain permettent aujourd'hui d'assurer la fonction cartographie basse altitude en figurant directement sur un écran, le relief, les contours, les lignes remarquables. L'utilisation d'écrans plats à cristaux liquide permet en outre d'éliminer l'effet, néfaste pour la lecture, du soleil direct sur les tubes cathodiques.

Un pilote peut disposer dès aujourd'hui d'une carte couleur à échelle variable sur un écran de navigation. Il pourra donc modifier son trajet en fonction des menaces mémorisées, en fonction du relief, en fonction de sa destination finale et compte tenu du trajet initialement programmé.

Un écran dédié à la navigation doit permettre au cargo militaire de se déplacer en haute ou basse altitude compte tenu de critères opérationnels mémorisés avant le décollage, voir remis à jour au cours du vol.

1 - 3 - La gestion des systèmes

Un moyen de type ECAM implanté sur A300/600, A 310, A 320 est de nature à garantir la sécurité du vol et la fiabilité de la mission :
La surveillance automatisée des systèmes de bord et la présentation des listes de manoeuvre en cas de panne, libèrent l'équipage des tâches subalternes de veille et lui permettent de se consacrer à la gestion du vol et à la surveillance des éléments spécifiques de sa mission :

- Communications avec le monde extérieur
- Relations avec la zone cargo
- Suivi du déroulement du vol.

Les systèmes de largages doivent être inclus dans la gestion assurée par l'ECAM en faisant apparaître la configuration de la soute, l'état d'avancement de la préparation au largage ou encore l'état d'arrimage du frêt embarqué.

Deux écrans dédiés à l'ECAM et une interface d'accès aux systèmes permettent d'assumer la gestion automatique des moyens de bord.

1 - 4 - Le contrôle du déroulement à l'aide des paramètres mission :

Ce déroulement s'effectue à l'aide des paramètres mission :

- Horaires estimés et suivi de l'itinéraire
- Carburant estimé aux points clés
- Itinéraires de repli prévus
- Choix des moyens de localisation
- Réception d'informations météorologiques relatives aux points de livraison, relatives aux aérodromes de destination ou de replis afin de réactualiser l'itinéraire le cas échéant.
- Réception d'informations opérationnelles relatives à chaque étape de la mission.
- Surveillance au poste des opérations de chargement/déchargement, des opérations de livraison.
- Comptes rendus au centre de contrôle opérationnel.

Il sera donc nécessaire d'installer :

A - Un moyen de communication hermétique, en vue d'assurer les liaisons opérationnelles bilatérales .

B - Un moyen vidéo fournissant au poste une vue directe sur les opérations de largage en cours.

Dans ce but, les moyens de type ACARS actuellement utilisés dans l'aviation civile peuvent être cryptés pour assurer la transmission de données.

Un des écrans systèmes doit être utilisé au cours du largage pour vérifier le bon déroulement de la séquence en cours.

1 - 5 - L'autoprotection de l'avion

Les dispositifs de détection de menace sont de deux types :

- Moyens TCAS développés dans le cadre de l'aviation générale pour alerter l'équipage vis à vis des trafics de proximité menaçants (en trajectoire) ou non.

- Moyens de décodage des impulsions radar pour en déterminer le caractère menaçant et moyens de détection de proximité de missile.

Ces moyens sont présentés actuellement sur des indicateurs spécifiques ; ce qui ne répond pas au besoin identifié de pilotage tête haute. Ces menaces doivent être présentées de façon immanquable dans le collimateur de pilotage afin de s'intégrer au besoin à court terme de réaction de l'équipage : manoeuvre évasive, et leurrage commandé manuellement si l'automatisme n'est pas en cours.

L'autoprotection de l'avion de transport futur peut reposer :

A - Sur une détection déclenchant un signal spécifique sur l'écran de pilotage tête haute

B - Sur un déclenchement automatique ou manuel des moyens de leurrage en fonction des conditions opérationnelles ambiantes : interface dédiée à portée de main des deux pilotes.

III- 2 - Les nouvelles interfaces en cours de mise au point

De nouveaux dispositifs de dialogue avec les calculateurs centraux sont en cours de mise au point. L'objectif est de simplifier l'accès du pilote aux paramètres de gestion du vol :

- Désignation instinctive de paramètres
- Facilités d'affichage de données
- Activation rapide des modes de fonctionnement autorisés des systèmes.

A - Tablette tactile

Elle permet par simple touché d'une tablette spécifique de désigner, sur un écran, un paramètre de conduite (IAS, Altitude, ou autre), d'en modifier la valeur de consigne par une manipulation instinctive simple et rapide ne nécessitant aucun apprentissage (balayage du doigt sur la tablette), et d'activer cette nouvelle consigne.

B - Ecran tactile

Un écran plat couleur propose un menu de modifications dont l'application est autorisée (nouvelles valeurs des paramètres de vol, nouveaux modes de fonctionnement des systèmes).

La sélection se fait par simple touché de la zone de l'écran portant la modification retenue. l'écran se reconfigure automatiquement en fonction des actions précédentes de l'équipage.

C - Commande vocale

Sa manipulation ne nécessite pour l'équipage que la pression sur un inverseur dédié (localisé sur le manche de pilotage par exemple).

Elle permet l'affichage de paramètres de consignes, l'activation de nouveaux modes de fonctionnement de systèmes.

Elle peut être installée en redondance d'une seconde interface manuelle (pilote automatique, ou afficheur de fréquence de radio communication par exemple). L'exploration actuellement en cours doit finaliser une philosophie d'implantation au poste.

D - Les aspects pénalisants effacés par ces nouvelles interfaces

La rédaction de consignes de vol par l'intermédiaire d'un clavier alphanumérique était apparue pénalisante sur les CDU mécaniques à tube cathodique actuellement proposées par les équipementiers.

L'implantation de touches dédiées à un mode de fonctionnement unique, dont l'accès n'est pas toujours autorisé, conduisait à la multiplication des commandes dont certaines étaient fréquemment inhibées.

De plus, il est apparu que les utilisateurs n'utilisait qu'une partie des possibilités des systèmes de gestion mission du fait de la relative complexité d'accès à certaines fonctions.

Ces nouvelles interfaces ont pour objectif d'éliminer ces défauts.

III - 3 - L'architecture nouvelle du poste de l'avion de transport militaire

3 - 1 - Les principes de conception

Cette architecture doit être optimisée pour :

- assurer les fonctions identifiées par l'examen du besoin opérationnel,
- faciliter la tache de l'équipage comparativement à ce qu'elle est aujourd'hui,
- diminuer les temps de formation des jeunes pilotes, et permettre la conduite du vol à deux : un pilote instructeur et un pilote en instruction.
- s'intégrer dans le domaine militaire en utilisant un système ARINC numérique BUS 1553

Le concept à retenir est :

- Un pilotage tête haute
- Une gestion mission tête basse
- Une reconfigurabilité maximale en cas de panne
- Des MTBF systèmes élevés.

3 - 2 - La fonction pilotage navigation

Le pilotage est assuré par une visualisation collimatée en tête haute dans un viseur holographique d'ouverture de champ : 30° x 20° au moins.

La navigation est assurée par un écran plat couleur assurant à la demande la fonction cartographie. Chaque pilote dispose d'un écran de navigation.

En cas de panne du collimateur, une image de pilotage peut être reconfigurée sur l'écran de navigation.

3 - 3 - La fonction gestion des systèmes

Un système ECAM propose sur deux écrans tête basse entre les deux pilotes un suivi automatique des systèmes de bord ; cet ECAM incorpore en outre la fonction chargement/déchargement, suivi du largage (état de préparation, déroulement des séquences).

3 - 4 - La fonction gestion de la mission

Elle est assurée par au moins une interface spécialisée à disposition de chacun des pilotes et qui permet :

- d'assurer les modifications de plan de vol (itinéraire, horaire, altitude).
- d'assurer les communications de contrôle aérien et opérationnelles.
- d'assurer le meilleur choix de localisation
- d'assurer l'affichage et l'engagement des tenues automatiques des paramètres de vol
- d'accéder directement à la prédiction des performances de l'avion
- d'accéder à la connaissance de l'état opérationnel de l'avion grâce aux auto tests internes de l'ensemble avionique.

III - 4 - Effet de la nouvelle conception de conduite avion sur les performances réellement atteintes en opération

4 - 1 - Détermination de la charge offerte optimale

Par nature, l'avion de transport militaire n'effectue que peu de lignes aériennes régulières.

L'équipage doit recourir au manuel d'exploitation pour calculer sa charge offerte sur chaque nouvelle étape de sa mission.

L'imprécision de lecture, la complexité d'élaboration des choix V1/VR, braquage volets, et puissance de décollage, conduisent évidemment les équipages à utiliser une méthode simplifiée non optimale mais sécurisée par une réduction systématique des charges offertes.

Le recours aux calculateurs de bord permet après insersion des paramètres opérationnels du jour (longueur de piste, coefficient de revêtement, vent, température) de connaître exactement les meilleurs paramètres de décollage pour une charge marchande donnée, ou de connaître la charge offerte maximale et les paramètres de décollage associés.

Ce calcul automatique pourra être reïteré au dernier moment afin de réajuster la charge embarquée compte tenue des données finales.
Il s'en suivra une réduction d'usure des moteurs puisque la puissance du maximale de décollage ne sera plus affichée que dans les cas ou la charge embarquée sera limitative, et il s'en suivra un accroissement des capacités de transport réellement mises en oeuvre.

4 - 2 - Précision de tenue des éléments de vol

A - Le FADEC

Cet équipement moteur garanti la plus grande précision des éléments de conduite moteur puisque l'action du pilote se résume désormais à l'affichage de puissances objectifs et que le FADEC assure l'automatisme qui conduira le moteur vers la puissance objectif affichée et selon la meilleure ligne de fonctionnement.

B - Les commandes de vol électriques

Ces commandes modifient la notion de pilotage, et améliorent la visibilité vers les panneaux frontaux

- Les commandes classiques permettent un pilotage en "assiette"
- Les commandes électriques permettent un pilotage en "trajectoire".

Sans action corrective permanente du pilote, il devient donc possible de stabiliser une trajectoire, les autres paramètres pouvant varier. La tache de l'équipage s'en trouve facilitée.

C - Le pilotage tête haute

Grâce à l'ouverture de champ optique considérablement accrue dans un collimateur (30° x 20°) par rapport aux écrans en tête basse, la lecture sera beaucoup plus précise et la densité des informations présentées sera réduite.
La tenue des éléments de vol pourra de ce fait être nettement accrue en précision et optimisée au cours des phases de vol délicates (poser, largage, décollage).

La figuration en tête haute d'un vecteur trajectoire devient parfaitement homogène avec les commandes de vol électriques.

4- 3 - Réduction des minima météorologiques nécessaires pour une livraison

A - Livraison par poser ou par largage à très faible hauteur

Il existe une relation directe entre la visibilité, la précision de localisation et le guidage assuré sur un HUD.

On peut donc définir des minima pour chacune des configurations de localisation en cours. La collimation à l'infini garantit l'acquisition visuelle la plus précoce de la piste et un recalage humain immédiat en cas de besoin.

L'approche autonome sans ILS ni MLS pourra être envisagée avec des minima faibles dès qu'une certitude existe sur la classe de précision de localisation.

B - Livraison par largage

Hors largage à très faible hauteur, tous les moyens définis précédemment assurent un guidage pour le largage sans la vue de sol, pourvu que la précision de localisation garantisse la chute de la charge sur la zone prévue.

IV- CONCLUSION

L'apport des nouvelles technologies développées pour l'aviation commerciale de transport et l'apport spécifique d'études militaires en cours permettent d'accroître le domaine d'emploi d'un avion de transport militaire

- En garantissant les meilleures charges offertes de l'avion
- En tendant à éliminer l'effet néfaste des conditions de visibilité.
- En facilitant la formation des équipages
- En réduisant les coûts d'exploitation : équipage à deux, gestion optimisée des rechanges, accroissement des temps de fonctionnement sans panne.

Une coopération européenne en vue de définir et construire les successeurs des C130 et C 160 ne devrait pas manquer de tenir compte de l'impact opérationnel des études en cours.

ADVANCED TECHNOLOGY APPLICATION IN THE FLIGHT DECK DESIGN FOR MILITARY TRANSPORT AIRCRAFTS.

AD-P006 246

by
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SUMMARY

The continuous growing in systems/functions installed in the modern aircraft, imposed by the more and more demanding requirements in terms of performance and safety, is leading to the development and the application of new components and systems in the area of cockpit indication and automatic controller integration.

The Cathode Ray Tubes (CRT) and other multifunction display techonologies are rapidly replacing many of the dials, panels and gauges of the old cockpit. Artificial intelligence and high level automation are emerging in digital avionics. These systems would take over the crew in many cockpit management functions such as reconfiguration to compensate fault or execute emergency procedures.

This paper analyzes the design & certification aspects related to the adoption of these new techonologies and discusses some aspects of human factor engineering which become an integral part for the cockpit design, for the simbology and for the logic integration of the function within the automatic control and display system. (25)

* Military aircraft. * Jet transport aircraft
* Flight decks.

1. INTRODUCTION.

Aircraft cockpit design has changed radically in recent years and will continue significantly in the next future.
The changes result primarly from advances in computer and display technology to reduce pilot workload and enhance flight safety. These developments produce an impact on the pilot interface with the aircraft system, as consequence of the intensive introduction of system automation in those area normally left to the pilot control: fuel, hydraulic, electrical systems, avionics, etc.
The flight deck is the aircrew's primary point of contact with the airplane. Unlike the rest of the airplane which is designed with the specific objective of exceeding human capabilities, the flight deck must be designed with the human limitations very much in mind. The use of new technology has been introduced to reduce pilot workload and make flight safer.
The new technology, particurarly at level of the micro- electronics, provides a greater number of design options than before, such a way that the designer has a large capability to "build up" systems around "crewmen".
In the past, new design was rarely considered entusiastically by the operators, due to the fact that new systems were designed taking in account above all the performance and technical requirements instead of operators needs and utilization. Today trend considers that new design and techniques shall improve not only systems performance but shall tailor pilot's requirement in terms of efficiency, safety, comfort, user learning. To achieve these aims the following criteria are to be considered:

- the arrangement of the fligth crew compartment shall be such as to ensure that the flight crew members will be able to perform all their duties and operate the controls in the correct manner, without unreasonable difficulty, fatigue or concentration;

- the arrangement of the crew compartment shall be such as to minimize the likelihood of injury to the flight crew members, both in normal operations and in emergency conditions (included landing).

Clearly the inclusion of the crewman as part of the system in most situations introduces particular problems due to human limits. Physical and mental workload, in crew members, are the limits of the performance of the man-machine system, where machines show superiority in terms of speed, power and the ability to perform multiple activities simultaneously. Therefore man and machine must match their limitations and capabilities in order to be considered complementary rather than competitive.
In common with most of the next generation of civil aircraft, the military aircraft should have a flight deck which can be operated by two pilots only. The impact of this requirement on the overall flight deck design concerns primarly the cockpit accomodation and consequently the automation, in such a way that functions previously operated by F/E, Navigator and other crew men can be centralized.
Research and industrial application are introducing a defined technology that is based on the utilization of sensors, displays and keyboards to simplify and reduce crew

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workload and minimise cockpit size. New screen technology (flat panels, HUD, Touch-sensitive), Area Keyboards with Direct Digital Keys and Direct Voice Inputs, Microprocessor Controlled Systems as Flight Management System (FMS), Ground Proximity Warning System, Centralized Alert Monitoring System (AMS) and Display Automation (DA) will permit to eliminate the third crew member, providing the pilots with all the information and aids necessary for a safe flight. The use of cockpit automation will improve pilot workload reduction too. Around this basic "core", cockpit configuration can enhance to ensure effective application of mission requirement to flight deck design.

This paper intends to discuss the problems associated to the application of an Automatic System Controller (ASC) integrated with an Automatic Monitoring and Alerting System (AMAS).

2. PILOT AND AUTOMATION.

Pilot's role and task are radically changed with respect to those ones that they have had in the previous generation of aircrat.

The continuous growing of the systems complexity has introduced a lot of knobs, switches, gauges and lights to operate and monitor the system; this contributed to augment pilot's workload. In the new cockpit the manual controls are diminishing and will continue to diminish, they will remain only as backup for safety considered tasks.

This introduces other problems and questions regarding crew takeover of control and training retention. The pilot will be no longer in control of the aircraft, but will be essentially a "flight manager" and a "supervisor" of the System Controllers which are in charge for him. Pilots have the information to make decision instead of data to analize.

Cockpit automation is addressed to exclude the pilot from the "information loop" so compromises were made to keep the pilot active. The major human factor concern expressed by pilots and other critics on the introduction of the automation in the cockpit is how "keep the pilot in loop".

An answer to this important problem could consist in providing the crew with a different and major amount of information utilizing electronic displays or interactive monitors, see figure 1.

3. DISPLAY AUTOMATION AND SYSTEM AUTOMATION.

3.1 General.

In the control theory, automation means that human function is replaced with machine functioning. In the specific application to the cockpit, automation means that some tasks before performed by the pilots are operated by computerized machine.

The pilot is assuming the role of manager and supervisor in the new automated cockpit. It is essential in this described picture that the pilot can take over on the machine if he judges that it is acting unsafely.

The tasks normally considered for automation application in cockpit of the last generation where essentially control type function, such as flight path guidance, electrical distribution management and environmental control.

The aircraft of the newest generation incorporates automation in many other areas like power plant (FADEC), navigation (FMS) etc. Reasons for this rapid development can be identified by the following:

- Technology available.
- Safety requirements.
- Increased Workload.
- Complex requirements for military missions.

Technology available.
The microprocessor revolution and the development of reliable high resolution displays certainly are the principal responsible of this development.

Safety requirements.
The effort of the designer to enhance the safety of critical functions results in an increased number of functions been automated, especially in those cases where the accident investigation proved that the primary responsibility of the accident was human error.

Increased workload.
The increased number of tasks demanded to the pilot in the flight of the modern civil and military aircraft produced an unacceptable level of workload. Certainly the automation, alleviating the pilot of part of the tasks, is used to reduce the final workload.

Complex requirements for military missions.
The increased demands for special mission, involving a multitude of countermeasure and reconnaissance system, whose operation is some time beyond the human capability, requires to introduce a lot of automation in the new developped systems.

3.2 Display automation.

As anticipated in previous paragraphs, the increased automation requires the introduction of new concept in the cockpit.

The current conception of the "glass" cockpit based on computer driven Cathode Ray Tube (CRT), has allowed to go beyond the constraint of conventional electromechanical instruments and of lamps type annunciators, that are limited in what they can do and present.

The incredible flexibility of the electronic displays allows the designer to inform the pilot of what are the actual limits for the system at the moment and to present the informations in format never used before: symbols, colors text and graphics, resulting in pictorial of the system presented clear and unambiguous. This presentation reduces, if not eliminates, the need of interpretation of the status of the system.

The figure 2 shows an example of synoptic associated to a generic system that can be presented on an electronic display.

Particular care is required in evaluating the amount of information to present to the crew in the specific flight time frame. There is a serious risk that the pilot can be over loaded with the presented informations, not always necessary for that particular situation, but absolutely required in case of system failure or automatic system reconfiguration (fig.3). In fact, with "soft" displays the pilots can select or deselect dedicated "Page" of the system examinated and find all kind of information required. This introduces another kind of automation: "display automation".

The concept behind this definition is "do not tell the pilot every thing but what he needs when he needs", of course leaving to him the authority for requesting more detail, operating particular selections if the phase of flight permits. This concept is realized in the definition of a new philosophy of caution and warning system as described in the next paragraph.

3.2.1 Automatic Alerting and Monitoring System.

The main function of an alerting system is to monitor the aircraft systems and to inform the crew if a failure occurs or if an unsafe condition is reached. As a consequence of the major automation introduced in the aircraft system, design of the alerting system is changed.

"Keep the pilot in-the-loop" if means inform the pilot of the status of the system, also means to let the pilot know what the automatic system is doing, or in case it is taking an action, if that is the one is supposed to be done. In other words it helps the pilot to monitor the "good" functioning of the ASC. This implies that the alerting system must be designed to be capable, in case of a generic aircraft failure, to inform the crew in two different ways in relation of the ASC operation, as illustrated in figure 4:

a) the failure occurred and the result of the corrective action taken by the automatic system controller

b) the failure occurred and the corrective action to be taken by the crew.

The use of the electronic displays greatly increased the possibility to define different message levels with different meaning in terms of pilot action required (as defined in ARP 450D) using color, shape and symbols.

The alert are generally classified in four different categories:

Level 3: associated to failures/conditions requiring immediate crew awareness and/or immediate crew action.

Level 2: alerts requiring immediate crew awareness but delayed action.

Level 1: alert indicating status or system malfunctions not requiring immediate awareness nor crew action. In this category are the messages associated to the automatic reconfiguration.

Level 0: indications related to selection considered normal for a short time.

Associated to the categorization indicated, different shape and color is attributed to the displayed messages, in order to facilitate the crew recognition.

The level 3 are presented in red, where the level 2 and 1 are amber, and in order to clearly inform the crew that an action is required a different shape is also used (box around the message or different symbol in the first position etc.).

Because of the flexibility offered by the new displays and computerized equipment, the number of messages will easy reach the many hundreds. A new problem is to be solved: cluttered display in case of cascade of failures. To solve this problem is necessary to identify for each failure the "genealogical tree", in other words the failure(s) generating and the one(s) that is generated. Then we have to build a grid of inhibitions that allows to display to the crew the message(s) associated to the originating failure only.

This feature, based on the "most significant alert" concept, results in a help for the pilot and contributes to reduce the workload.

To give an example, in case of an electrical bus failure, many other system powered by that bus will fail, resulting, in the old cockpit, in a number of indicators illuminated, and the capacity to find the originating problem and to apply the appropriate procedure depends on the crew ability.

Using the new concept, the computer is programmed in a way that in case of the above failure only the "generator bus" failure is presented to the crew on the main alert list, where the consequent failures are indicated in a secondary alert list.

The pilot will have to apply the correct procedure.

This process of "inhibiting" the alerts when they are consequence of other failures, is extended also to the case when the alert (the failure condition) is normal for that status of the system.

As an example, because it is normal to have engine oil pressure low when the engine is not running, the associated message is inhibited during that condition. The application of the above concepts associated to the use of programmable displays, where the messages are written in clear letters, improves the recognition of an anomalous condition, eliminates the possibilities of a misinterpretation and contributes to reduce the workload.

3.3 System automation.

As anticipated, we are going to discuss the automation associated to the utility systems of the airplane. The benefits of this type of automatic control can be indicated in increased safety and reduced workload. The crew operation of these systems can be divided in two different types:

a) Normal operation: for example the activation of fill fuel pumps to balance the airplane or adjust the center gravity.

b) Abnormal procedures: for example turn off a failed component.

The first idea is to replace the paper check list with one electronically generated and presented on a dedicated display.

The pilot has not to find the procedure to be applied to the specific failure, the computer will find for him. The auto selection, taking in account the phase of flight and the prioritization for multiple failure, can be considered.

The result is an high complexity with a little workload saving and no safety increase. The pilot manually takes corrective and delayed action and no clue for the pilot if is pushing the wrong button.

The other solution is to implement the normal and abnormal "procedure" in a microprocessor based system in order to completely discharge the pilot of the task to operate these aircraft systems. The problem to be solved, in this type of approach, is the protection of the aircraft against possible unsafe conditions caused by erroneous actions taken by the automatic controller, without crew capability to be aware of recovery. An indipendent Alerting System, which monitors the ASC operations, and a series of hardware and software protections can be the answer.

The reversion to the totally manual mode of operation shall be guaranteed to the crew in any condition and even the ASC shall revert to the manual mode if a predefined unsafe configuration for that system is recognized.

If the total loss of the hydraulic power is considered a critical condition, the controller shall revert to the manual mode of operation if the next required action causes that condition, the manual reversion shall always be associated with a predefined aircraft system reconfiguration considered safe. The figure 5 illustrates schematic architecture for an Automatic System Controller, integrated with displays and overhead panel.

Each system controller has two identical channels, with same microprocessor and using the same software. Only one channel is in control at all time, with the other one in "stand-by".

When a failure is detected the channel in control switches to the other one. If both channels fail the controller reverts to manual. To avoid the risk of the aircraft completely operated manually, separated controller for each system has to be considered. But the next step will be many controllers located in a same "fail safe" computer with the advantage of simplified interface between the different systems.

4. CONCLUSIONS.

Today the pilot is a supervisor of the automatic systems and his workload needs to be reduced: therefore, design engineers are gathering certain operational decisions into the software to allow pilots to decide what the system automation have to "tell" him, above all flight phases, during critical phases such as takeoff or systems reconfiguration after a failure.

Although we have described many real benefits to be derived from automation, it is not sufficient justification for doing so everywhere and everytime. In some instances, the decision to automate some or all of the components of a man-machine system is based on a desire for increased safety or reliability, by reducing the opportunity for human error. Automation may derive also from a desire to avoid excessive workload, or may be provided to improve performance. Finally, there may be economic reasons for automation such as fuel efficiency, reduction in crew complement and reducing maintenance or extensive ground support.

Some of the potential reasons for automation include a reduction in operator skills and systems understanding, but limiting, on the other hand, operators' abilities to respond in a timely way when the unexpected occurs. In addition, operator inactivity might be increased by automation.

Some of these problems might be avoided by applying automation more selectively by providing operators with additional training or meaningful activities to maintain their involvement in the system control. Operators must evaluate the automated systems; if the systems are safe, reliable and allow operators to interact naturally with the state of the system, many potential problems might be avoided.

In the future, the use of touch-screen controls may improve pilots confidence with systems beacause it will be easier the utilisation of the display means by touching a screen than entering data with a keyboard as the current technology permits.

In conclusion, what has been discussed and described represents today state-of-art, in some of the most modern, both military and civil, applications. Clearly, due to increased use of electronics, new theories and design could arise in a near future and cockpit design and automation application could continue to change at a "swift pace" to process complex integration in display information, function selection and controls.

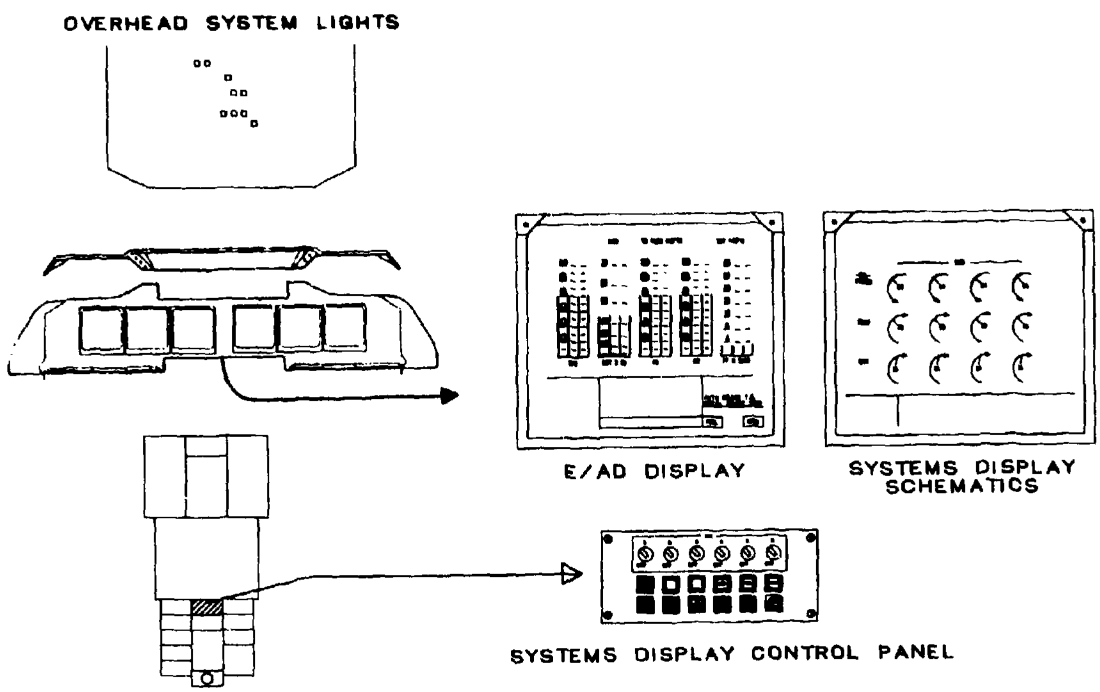


FIG. 1 - A MODERN COCKPIT

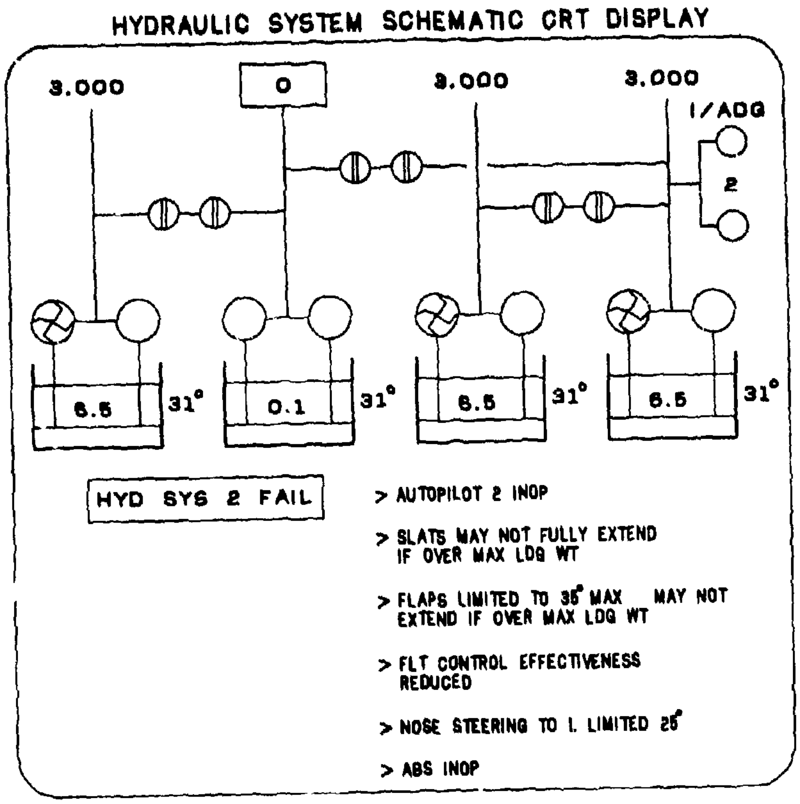

HYDRAULIC SYSTEM SCHEMATIC CRT DISPLAY
3.000
0
3.000
3.000
1/ADG
2
6.5
31°
0.1
31°
6.5
31°
6.5
31°
HYD SYS 2 FAIL
> AUTOPILOT 2 INOP
> SLATS MAY NOT FULLY EXTEND IF OVER MAX LDG WT
> FLAPS LIMITED TO 35° MAX MAY NOT EXTEND IF OVER MAX LDG WT
> FLT CONTROL EFFECTIVENESS REDUCED
> NOSE STEERING TO L LIMITED 25°
> ABS INOP

FIG.2

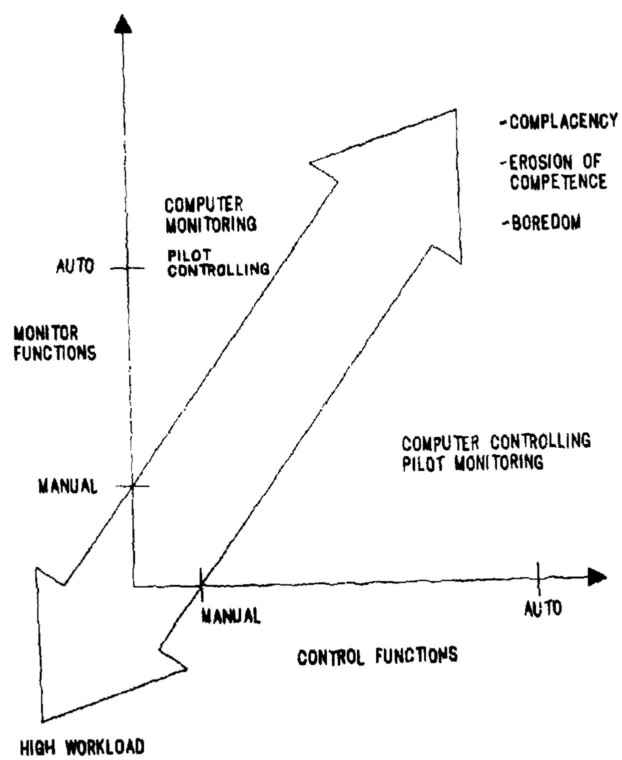
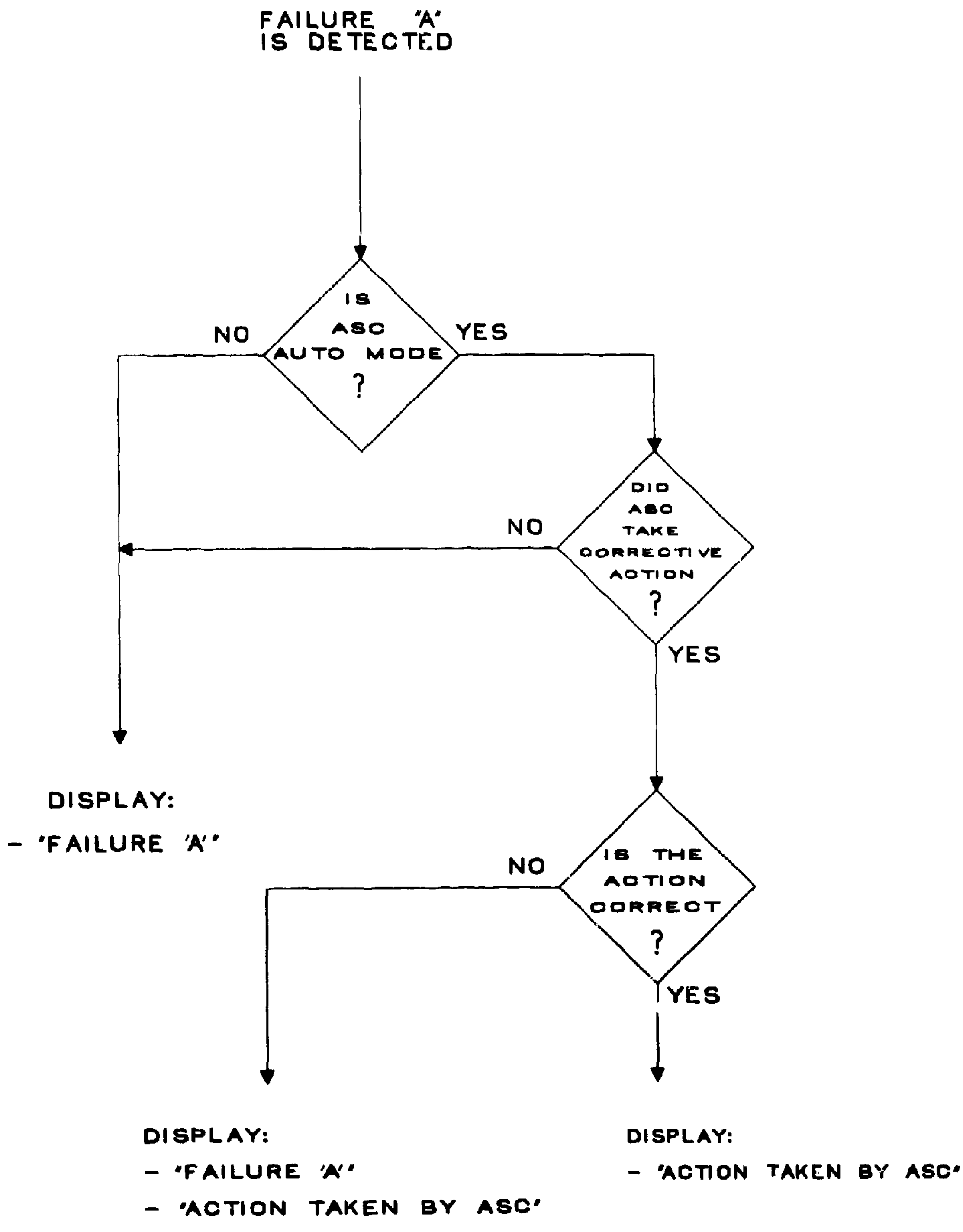

-COMPLACENCY
-EROSION OF COMPETENCE
-BOREDOM
COMPUTER MONITORING
PILOT CONTROLLING
AUTO
MONITOR FUNCTIONS
COMPUTER CONTROLLING PILOT MONITORING
MANUAL
MANUAL
AUTO
CONTROL FUNCTIONS
HIGH WORKLOAD

FIG.3



ALERT PRESENTATION PHILOSOPHY

FIG.4

ASC SYSTEMS

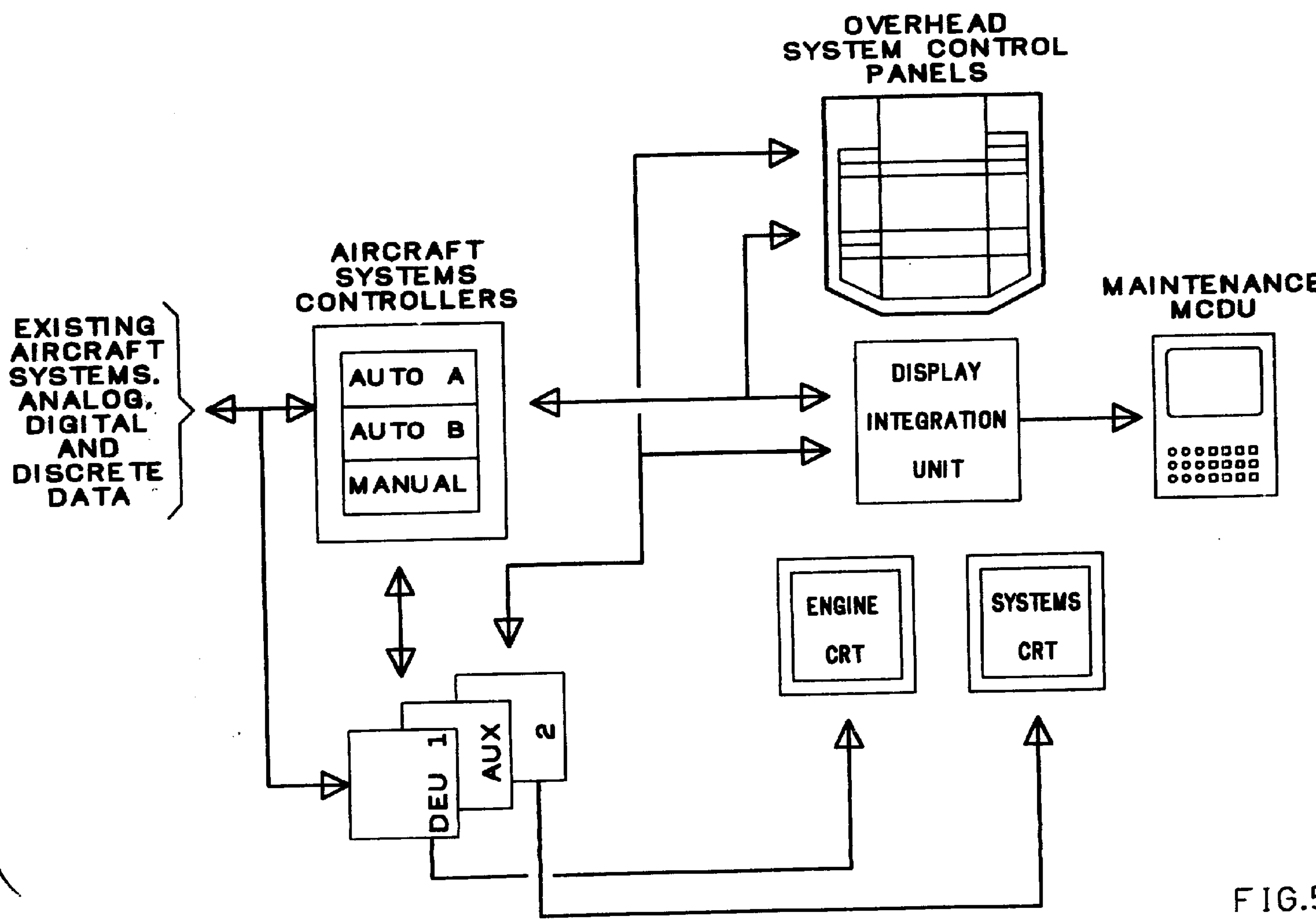


FIG.5

C-17 Piloted Cockpit Testing

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The C-17 aircraft under development will have a worldwide airlift mission in both combat and peacetime environments. With only two pilots in the cockpit, (eliminating the navigator and flight engineers, standards of Military Airlift Command (MAC) operations) design and testing must be logically thought out and executed to enhance mission completion and reduce the pilot's workload. Numerous test facilities are being used to test the state-of-the-art avionics, its interface with the pilots, and the ability of the pilots to accomplish this mission.

25 * Jet transport aircraft, * Cockpits, * Pilots, C-17 aircraft.

I. C-17 MISSION AND CREW CONCEPT

The C-17 advanced transport being developed by Douglas Aircraft Corporation (DAC), Long Beach, California, will be a four engine turbofan aircraft capable of airlifting large, outsize payloads over intercontinental ranges with or without aerial refueling. Thus, the C-17's mission is worldwide airlift of US combat forces, equipment, and supplies. The C-17 will deliver passengers and outsize/oversize/bulk cargo over intercontinental distances, provide theater and strategic airlift in both the air-land and airdrop modes, and augment aeromedical evacuation and special operations missions. It will provide the flexibility to easily transition between these delivery modes by allowing rapid inflight reconfiguration. Its biggest contribution to the present airlift system will be long range delivery.

The direct delivery characteristics of the C-17 offer an important additional advantage. The C-17 can routinely operate in the theater role currently limited to the C-130 and dramatically improves strategic deployment capability as well as theater movement of forces and sustainment. The C-17 offers warfighting commanders the flexibility to respond to both theater and strategic airlift requirements. One of the unique roles for the C-17 is the delivery of outsize combat equipment/cargo directly into a austere airfield.

There are numerous significant features on the C-17 that take advantage of advances in today's technology. These include the following: supercritical wing design and winglets to reduce drag, increase fuel efficiency and range and minimize the amount of ramp space required; receiver inflight refueling capability; externally blown flap configuration, direct lift control spoilers and high impact landing gear system, which contribute to the aircraft's capability to operate into and out of small austere airfields; forward and upward thrust reverser system that provides backup capability, reduces the aircraft ramp space requirements, and minimizes the interference of dust, debris, and noise on ground personnel activities; cargo door, ramp design and cargo restraint systems that are operable by a single loadmaster and permit immediate equipment offload without special handling equipment; two man cockpit with cathode ray tube (CRT) displays that reduce complexity and improve reliability; a mission computer to manage pilot workload, navigation tasks, and integrate all avionics inputs; maximum use of built-in-test (BIT) features to reduce maintenance and troubleshooting times; and walk-in avionics bay below the flight deck that improves accessibility. (See Appendix A)

Two requirements drove the cockpit design: short field landing and life cycle cost. Short field landing with a large transport aircraft means being able to routinely land and stop in 3000 feet. To accomplish this, the aircraft must reliably touchdown as close as possible to the leading edge of the runway. This allows the aircraft to use all the remaining runway to stop the ground roll. Experience on the DAC YC-15 program in the 1970's demonstrated that pilots could land significantly closer to the runway leading edge by using a steeper 5 degree glide slope rather than the normal 3 degree glide slope. The pilots had to "aim" the aircraft and fly it to a spot on the ground. This technique required the use of a Head-Up Display (HUD). Life cycle cost was reduced by decreasing the number of crewmembers and increasing the reliability of the information systems, i.e., computers and electronic displays. This required greater in-cockpit visibility, made the yoke obsolete, and in essence, made the cockpit overhead panel become the flight engineer.

A key critical feature that resulted from reducing the life cycle cost is the two pilot cockpit concept. By fully integrating and simplifying pilot tasks, two pilots can handle the requirements of both the diverse missions described above. The key point is to obtain confidence that the two pilots can in fact handle all requirements before actually flying the aircraft. This will be accomplished through a thorough ground test program with the pilots as an integral part of the evaluation process.

In order to prepare for the pilot tasks and workloads to be exhibited in both

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developmental (DT&E) and operational test and evaluation (OT&E), the pilots must be an integral part of the ground testing and development effort. This must include not only DAC pilots, but test pilots and operational pilots from the "user."

"Pilot-in-the-loop" testing is essential before actual flight test. To this end, the Air Force and DAC have developed and used numerous simulation devices for advanced DT&E pilot evaluations. Motion based simulators (DAC's Motion Based Simulator, NASA's Vertical Motion Simulator, and the Air Force Flight Test Center's Test and Evaluation Mission Planning Simulator) are being used to evaluate the pilot and flight control systems interplay. An Integrated Display Development Station (IDDS) is being used to evaluate pilot workload, display symbology usefulness, and human factors. A pilot-in-the-loop simulator to evaluate all software, avionics, and the pilot interfaces, is present in the Flight Hardware System (FHS). The Flight Control System Simulator (FCSS) is testing actual pilot inputs to mechanical, hydraulic, and electrical components and their responses.

The aggregate of all these facilities and their associated evaluations and tests is leading to the thorough preparation of the C-17 for actual flight operations. The cockpit design and utility have been evaluated and pilot workloads have been detailed, simplified and refined. The flight control system and pilot interface is being evaluated and the total system integration, to include pilots, will have been thoroughly explored before flight test. This type of attention and pilot involvement will make the C-17 eminently qualified to perform its multitudinous roles. This paper will describe these facilities and the associated pilot evaluation techniques.

II. THE C-17 COCKPIT

The C-17 cockpit has been designed to reduce the number of crewmembers on Military Airlift Command (MAC) missions. Thus a pilot and co-pilot will handle all piloting responsibilities as well as those previously accomplished by a navigator and a flight engineer. Thus, the MAC pilots will need a more sophisticated cockpit which can permit them to maintain the proper situational awareness and still successfully perform their mission. The introduction of a HUD as the primary flight instrument and a "glass cockpit", one containing many computers and CRT displays, are being used to reduce the pilot workload. (See Appendix B)

a. Current Configuration

The heart of this cockpit design is the Mission Computer (MC), which enables the C-17 pilots to handle the myriad of tasks required to accomplish their mission. Three redundant MCs continually cross-check each other and can provide the pilots with information on flight planning, system performance, aircraft and avionics status and execute required functions to accomplish the mission, e.g., navigation. These computers are accessed manually using a keyboard.

The cockpit is arranged for optimum visibility of all displays, instruments, and controls by either pilot. (Figure 1) The instrument panels are designed with a "display by exception" philosophy, i.e., other than primary displays, only switchs, lights, or instruments that identify an out-of-tolerance condition will be lit. The most obvious cockpit design features are as follows:

- The use of a HUD is to provide the pilots with visual guidance for precise flight path control and minimal touchdown dispersion. The HUD is a primary flight instrument permitting the pilots to maintain visual reference outside the cockpit during critical phases such as landings, combat extractions and the Low Altitude Parachute Extraction System (LAPES) missions.

- The use of control sticks rather than yokes to provide the pilots with a better view of flight instruments and displays.

- Four Multi-Functional Displays (MFDs) that provide mission and aircraft information. (See Appendix D) The MFDs can be set for five basic formats with submodes for four of these as follow:

MFD Functions	Submode
Primary Flight Display	None
Navigation Display	Map Chart Compass
Plan Position Indicator	Station Keeping Radar
Engine	Normal Expanded Secondary
Configuration	Surface positions

Standby indicators for attitude, altitude, airspeed, engine and other flight critical conditions may be used if the MFDs are displaying other information.

b. Evolution of Design

The cockpit configuration was the result of gradual evolution and analysis. It involved five alternate configurations with many variations of each. The basic console configuration (Figure 2) included the four CRTs for the Mission Computer. The key to the cockpit development has been the increased emphasis placed on the HUD as the primary flight instrument. It is integral to pilot tasks, not an ancillary instrument.

The C-X proposal cockpit, presented in January 1981, (Figure 3) included six "B" size (i.e., 4" x 4" glass size) CRTs in groupings of two. These CRTs would make the C-17 cockpit a state-of-the-art glass cockpit. This cockpit included dual, limited capability HUDS, which were only Visual Approach Monitors (VAMs), limited to VFR approaches where the pilot can see the ground. It used a stabilized horizontal line, depressed for the approach angle, to monitor his glide path. The displays were grouped in Vertical Situation Displays (VSDs) and Horizontal Situation Displays (HSDs). The VSD and HSD displays were fixed and could not be changed. The VSD contained primary flight data like altitude, attitude, airspeed, and heading. The HSD gave a overhead map display with waypoints, compass, and heading information and lateral deviation.

Evaluation of the C-X arrangement revealed limited switching capabilities between the CRTs, inadequate CRT display size, installation problems, and lack of pilot flexibility. Subsequently, four new arrangements were proposed and evaluated during 1984.

The first alternate comprised six CRTs in groups of two. Four were D (6" x 6" glass size) CRTs and two were B CRTs. The proposed HUD remained unchanged (Figure 4). Two VSDs and two HSDs were made the larger D CRT while the two smaller B CRTs were changed to MFDs. These MFDs were capable of switching between different display formats. A second alternative used six D CRTs next to each other (Figure 5). Again, there were two VSDs, two HSDs, and two MFDs, but all were now the large size CRT.

Both of these alternatives put HSD and VSD on a larger format and allowed peripheral pushbuttons on the D display. However, the cost was the most expensive of all alternatives and the cockpit appeared crowded. There was no space for growth on the instrument panel and the 2D-2B-2D format presented interchangeability problems due to noncommon CRTs. It moved standby instruments to one side and deleted one set of standbys.

The third alternative used 5D CRTs (Figure 6), with two VSDs, two HSDs, and one MFD. The HUD remained the limited capability VAM from the proposal. This configuration offered all the advantages of the previous two alternatives, plus allowed space for growth, bigger D displays at all positions, interchangeability, and a convenient grouping of pilot essential instruments around the MFD. However, cost was still high and the five CRT arrangement led to an undesirable, unbalanced arrangement. It presented only one CRT common to both pilots and still deleted one set of standby instruments.

The final alternative presented four MFDs using the D CRT (Figure 7). The 1-2-1 arrangement allowed pilot flexibility, reduced the total number of CRTs, balanced the arrangement, reduced pilot workload and provided growth space and space for dual sets of standby instruments. It allowed dual standby instruments. Additionally, this alternative proposed fully capable HUDs, a new idea for transport aircraft. This full-up HUD would include functions necessary for the C-17 mission, i.e., guidance for LAPES, and approach guidance into Small Austere Fields (SAAF), allowed full envelope head up operation, provided additional mission capability and still retained HUD growth capability. However, DAC was uncertain the Air Force would accept the full capability HUD. Additionally, DAC would have to pioneer by developing the HUD format for a large transport with the C-17's tactical missions.

This last alternative was accepted by the Air Force in 1985 and is basically today's C-17 cockpit arrangement. This arrangement allows all required operations, redundant capability through the MFDs, better pilot accessibility, reachability and readability, less LRUs with more interchangeable parts, and flexibility for future growth. The HUD has become the primary flight display. The pilot flying the C-17 uses the HUD and has his Navigation Display head-down, i.e., does not simultaneously display his primary flight display on his MFD. He can use HUD information to keep his head outside the cockpit and fly the same procedures, whether VFR or IFR. The pilot not flying will use the primary flight display and may stow the HUD.

With this approach each pilot has a primary flight display and Navigation Display, and shares a common engine display. Each pilot has his own full-time HUD, standby attitude indicator, standby altitude/airspeed indicator and a Bearing Distance Heading Indicator (BDHI). One center MFD is always set to monitor engine instruments. The HUD now displays the primary flight display data necessary to fly the C-17. MFD functions are shown in Appendix D. The HUD also has two declutter modes so that during peak workload periods, the pilot can remove unnecessary data and simplify the display.

Thus, the C-17 pilot flying has no need to transition from heads down to heads up. By using the HUD as the primary flight instrument, he eliminates the transition, eases his workload, and has the added advantage of flying any VFR or IFR approach using the same procedures. Thus weather, phase of the complex airdrop/cargo mission, or type of approach become irrelevant factors in flying. This concept is new to the military transport aircraft world, but will not remain so. All transport aircraft of the future should use this concept as the aircraft can be operated more safely and consistently by the pilot. The C-17 and its HUD and glass cockpit are definitely paving the way for the future in all military and transport aircraft.

III. ADVANCED DT&E PILOT EVALUATION TOOLS

This section describes numerous test and simulator facilities. These are owned and controlled by various agencies, each of which has control of release of information pertaining to their individual facility. All contribute to giving pilots confidence in various aircraft system capabilities before initiation of the flight test program.

a. Integrated Display Development Station (IDDS)

The IDDS is owned and operated by DAC at the Long Beach, California (CA) facility. This is a motionless cockpit simulator to evaluate cockpit displays, pilot workload, and interface of the crew with the displays. It is particularly useful in evaluations of symbology on the HUD, the MC and all CRT displays. Operational and test pilots have been involved in these evaluations for years and have provided the baseline human factors engineering information that will allow the varied number of complex C-17 missions to be successfully flown.

The IDDS has a computer generated, exterior visual display which is instrumental in allowing pilot evaluations. Using the HUD, MC and the rest of the glass cockpit, C-17 pilots have "flown" routine takeoffs, landings, airdrop missions, parachute extraction missions, and air refueling tasks. These missions have included five degree approach landings, crosswind landings, day and night flight conditions, IFR and VFR flight, formation flying and others.

The IDDS supports the C-17 program by providing information to meet the following objectives:

- Evaluate and advise program management on the operational utility and suitability of the C-17 cockpit design.

- Evaluate pilot operational procedures, flight manuals, and checklists.

- Evaluate the pilot workload.

b. Flight Hardware Simulator (FHS)

The FHS is owned and operated by DAC at Long Beach. The FHS is a fixed base simulator facility under development and construction which will provide the C-17 design, and test and evaluation teams the capability to integrate the total avionics suite to the electronic flight controls via actual C-17 electronic multiplexing units. Systems level testing, i.e., testing of all avionics working together simultaneously as during actual flight, will be tested in the FHS. A key feature is that the FHS will also allow pilot-in-the-loop avionics evaluations using actual C-17 avionics hardware and software. This facility will provide pilots the closest cockpit conditions to actual flight before the flight test program.

The FHS supports total avionics integration through five objectives:

1) Provide the simulation capability to support verification of the avionics design.

2) Provide evaluation of the operator and system responses to selected faults or failures. (See Appendix C)

3) Use actual C-17 production configurations to provide actual avionics hardware and software interface with the "1553" multiplex bus.

4) Provide the necessary controls and displays to give the pilot a realistic cockpit environment with which to evaluate the integrated production avionics for selected missions.

5) Provide the flight crew with a realistic workload and flight familiarization before commencing the flight test program.

c. Motion Base Simulator (MBS)

This test facility is owned and operated by DAC at the Long Beach facility. It is a six degree of freedom, motion simulator which allows evaluation of piloted tasks in a limited envelope. It is primarily used to develop and evaluate C-17 flying qualities and the C-17 Flight Control System (FCS). Additionally, it is a useful tool in evaluating failure modes, for pilot training and first flight preparation and validating simulator models to be used by the Air Force as air crew trainers.

The heart of the MBS is the ELXSI computer. This simulates aircraft handling characteristics, provides the C-17 predicted aerodynamics, and produces aircraft engine effects, weather conditions and the coupled control surface movements to be expected from pilot inputs as a result of the aforementioned characteristics. Using a limited visual display, DAC and USAF pilots fly tasks controlled by FCS engineers. These tasks can range from cruise trim points to crosswind landings.

In 1989, the MBS underwent an upgrade to enhance its test usefulness. State-of-the-art actuator and hydraulic seals were installed along with a stand alone hydraulic power source. All new electronics include servo amplifiers, a microprocessor controller, fail safe systems and new motion drive software. All these improvements resulted in a more reliable, more responsive and accurate MBS.

The objectives of C-17 testing in the MBS are as follows:

1) Develop and verify control laws for the stability and control augmentation system of the FCS.

2) Pilot evaluations of simulated C-17 handling qualities as they are developed and refined.

3) Evaluate failure modes, cross-wind capabilities and flight characteristics near the ground.

d. Vertical Motion Simulator (VMS)

The VMS is owned and operated by the National Aeronautics and Space Administration (NASA) at its Ames Research Center in San Jose, CA. This is a six degree of freedom, large amplitude, high fidelity motion simulator. It offers computer generated visual displays, and a cockpit type (cab) enclosure that can be reconfigured to meet the user's requirement. C-17 testing was done in the transport cab, shared with the NASA space shuttle.

The VMS was used in 1988 and 1989 to develop and evaluate C-17 flying quality and the FCS. Failure state testing was accomplished as was development of special techniques to enhance handling qualities. All testing was done with test pilots from DAC, NASA Ames, and the USAF.

e. Flight Control System Simulator (FCSS)

The FCSS is owned and operated by DAC at Long Beach. The FCSS is a steel framework (iron bird) on which most of the aircraft's hydraulic and mechanical components are mounted in their correct vertical positions. To conserve space, the fuselage has been shortened over 42 feet. However, all hydraulic and electrical line lengths are the same as on the actual aircraft.

Simulated control surfaces, i.e., ailerons, elevators, rudders, spoilers, flaps and slats, are mass balanced to replicate the actual control surface. This allows actual measurements to be made of control surface deflections versus pilot inputs. The FCSS tests the integration of all these mechanical systems with the hydraulic, electrical and flight control systems. All components, subsystems and systems will be production units.

Planned upgrades to the FCSS include a second ELSXI computer to provide a simple pilot visual display, simulating airloads on control surfaces and an upgrade to pilot cockpit displays to allow more realistic pilot evaluations. Objectives of the FCSS testing include:

- Qualification of the hydraulic system used with flight controls.

- Evaluating transients during changes from electronic to manual FCS control.

- Investigating failure modes of the hydraulic system.

- Evaluation of pilot interaction with all represented systems.

f. Test and Evaluation Mission Planning Simulator (TEMPS)

This facility is owned and operated by the USAF at the Air Force Flight Test Center (AFFTC), Edwards AFB, CA. It is a six degree of freedom, motion simulator allowing evaluations of pilot tasks in a restricted aircraft envelope. It is used for all flight test programs conducted at Edwards AFB. AFFTC computers store simulated aerodynamic data along with aircraft handling qualities, engine characteristics and other information for the aircraft undergoing flight testing.

For the C-17 program, the TEMPS will be used immediately before and during the flight test program. It's usefulness is reflected in the following objectives:

- Edwards flight crew familiarisation with C-17 expected responses and handling qualities immediately preceeding every new phase of flight testing.

- Post-flight comparison of actual with predicted responses leading to refined simulation and possible improvements in the C-17 system itself.

IV. PILOT EVALUATION TECHNIQUES

Pilot evaluations have occurred in all these facilities. Both quantitative and qualitative information has been obtained.

Qualitative evaluations by pilots in the form of questionnaires, debriefings, Cooper-Harper evaluations, meeting discussions, and written reports can be accomplished on all facilities. This type of information is particularly valuable in the IDDS for cockpit and pilot workload evaluations. This information was extremely valuable during the evolution of the cockpit and HUD design.

Quantitative data is also obtainable in all facilities. Engineers work closely with the pilots to develop meaningful test cards. The simulators provide numerical feedback on all accomplished tasks which is then correlated with pilot qualitative comments. This type of data has been proven invaluable in FCS testing in the MBS, VMS, FCSS and FHS.

V. SUMMARY AND CONCLUSIONS:

The United States Air Force and Douglas Aircraft Company have designed the C-17 test program to simulate actual flight conditions as closely as possible before actually flying. This is doubly important as the pilots in the C-17 cockpit will be extremely busy. Therefore, simulations must concentrate both on avionics integration and cockpit evaluations. There are facilities to evaluate pilot workload, cockpit symbology, and the man/machine interface, i.e., the IDDS and FHS. Other facilities such as the MBS and VMS concentrate on FCS development and evaluation. The FCSS, FHS and TEMPS look at the avionics integration and the interface between the pilot and the C-17 systems. By working through a well-thought-out test program using these facilities, the C-17 developmental effort can be accomplished before the start of flight testing, with a cockpit, procedures and systems that the pilot can be comfortable with.

The evolution of a well-thought-out C-17 cockpit design has led to a four MFD, two HUD configuration that is the wave of the future. The C-17 HUD is designed as the primary flight director, allowing the pilot flying the aircraft to maintain his focus outside the aircraft, regardless of the weather or the phase of the mission. This concept is new to the large transport world, but will not remain so. The C-17 is leading the way for all aircraft of the future. The C-17 cockpit controls and displays are configured and designed to enable the C-17 to successfully perform its mission of worldwide airlift of US combat forces, equipment and supplies, whether over intercontinental distances or within a theater.

APPENDIX A

C-17 Capabilities

Key Features: The C-17 is required to have the following functional capability to accomplish its mission:

- Transporation of outsize/oversize/bulk cargo.
- Transporation of nuclear cargo.
- Air refueling.
- Adverse weather, day/night operations.
- Airland and airdrop/LAPES airdrop operations of 60,000 lbs rigged loads.
- Personnel airdrop operations at high/low altitudes.
- Combat offload.
- Transportation of mixed loads to include troops.
- Aeromedical evacuation.
- Small Austere Airfield (SAAF) operations.
- Worldwide operations to include medium threat environments.
- Reliability, maintainability, and availability.

Interfaces: The C-17 is required to interface with these systems to accomplish its mission:

- Air traffic control, navigation, and station keeping systems.
- Military command, control and communications systems.

- Defense Mapping Agency (DMA) Digital Aeronautical and Flight Information System (DAFIS) data base.
- Air Force Global Weather Central (AFGWC) computer flight plans.
- Ground forces/material handling equipment.
- Ground servicing to include ground defueling to Army systems, maintenance and logistics systems.

Unique Characteristics:

- Electronic flight control system.
- Electronic engine controls.
- High impact landing gear.
- Direct lift control with externally blown flaps.
- Nominal flight crew size of two pilots and one loadmaster to accomplish all airland/airdrop missions.
- Fully mission capable Head-Up Display (HUD).
- CRT display of navigation and flight attitude information.
- Majority of avionics integrated through mission computer.
- Use of On-Board Inert Gas Generating System (OBIGGS) for fuel tank inerting.
- Cockpit automation through the mission computer and warning and caution system.
- Ruggedized Laptop Computer (RLC).
- Night Vision Goggles (NVG) compatible cockpit.

APPENDIX B

C-17 Cockpit Controls and Panels

Left Additional Crew Member (ACM) Console

Headset Receptacle Panel
Intercommunication System Panel
Oxygen Regulator

Pilot's Console

Headset Receptacle Panel
Utility Light
Nosewheel Steering Handle
Inter Communication System Panel
Oxygen Regulator

Instrument Panel

Avionics Switching Control Panel
Bearing Distance Heading Indicator
Multi-Function Displays
Standby Altimeter/Airspeed Indicator
Standby Attitude Indicator
Total Fuel Used Indicator
Split Axis, AP/ATS Annunciators
Brake Pressure Indicator
Alternate Brake System In Use Indicator
Anti-Skid Switch
Standby Engine Display Panel
Horizontal Stabilizer/Rudder Trim/Aileron Indicators
Landing Gear Panel
Flap Position/Index Indicator
Speed Brake Indicator
Slat Extend/Slat Disagree Annunciator
Clocks
Mission Computer Switching Control Panel

Glareshield Panel

Glareshield Warning Indicators
Communication Navigation Control Panel
Engine Fire Extinguishing Handles
Fire Extinguishing Agent Low Annunciators
Automatic Flight Control System Panel
Instrument Lighting Control Panel
Head-Up Displays
Floodlight Dimmers

Overhead Panel

Communications Panel
Flight Control System Actuator Panel
Internal Lighting Panel
Backup UHF Communication Control Panel

Backup VHF Communication Control Panel
Wing Inerting Panel
Auxiliary Power Unit Control Panel
Electrical Control Panel
Landing/Taxi Lighting Control Panel
Environmental System Control Panel
Hydraulic System Control Panel
Fuel System Control Panel
Ground Proximity Warning System Panel
Bailout Alarm/Stall Warning Test Panel
Anti-Ice Control Panel
External Lighting Panel
Warning Annunciation Panel
Inertial Reference Unit Control Panel
Fire/Smoke Detection Annunciator Panel
Personnel Warning Signs Control Panel

<u>Copilot's Console</u>

Headset Receptacle Panel
Utility Light
Intercommunication System Panel
Oxygen Regulator
Oxygen Quantity Indicator
Oxygen Cross Feed Switch

<u>Right ACM Console</u>

Headset Receptacle Panel
Oxygen Regulator

<u>Pedestal</u>

Mission Computer Displays
Mission Computer Keyboards
Multi-Function Control Panels
Passenger Address Panel
Cabin Pressure Indicators
Cabin Pressure Control Panel
Engine Throttle Controls
Flaps/Slats Control Module
Aerial Delivery System Control Panel
Identification Friend or Foe Panel
Alternate Trim Control Panel
Trim Select
Pedestal Lighting Control Panel
Weather Radar System Control Panel
ACM Intercommunications System Panel
Parking Brake Control
Flap Index Selector Switch

APPENDIX C

Fault Insertion Candidate Table

1. Single Engine Failure
    a. engine out
    b. loss of ability to control engine thrust at any EPR
    c. engine fire

2. Ground and flight spoiler system failures
    a. jammed surface (any single spoiler)
    b. broken linkage
    c. loss of hydraulic power

3. Elevator system failures
    a. jammed surface (complete surface)
    b. jammed surface on only one side
    c. broken linkage
    d. loss of forward load feel spring

4. Horizontal stabilizer failures
    a. jammed surface
    b. runaway surface

5. Aileron system failure
    a. jammed surface
    b. broken linkage
    c. loss of load feel spring

d. loss of hydraulic power

6. Single thrust reverser failure

7. Asymmetric/split trailing edge (TE) flaps

8. Asymmetric leading edge (LE) devices

9. Flaps (TE/LE) devices fail to extend/retract

10. Antiskid fails

11. Brakes fail

12. Loss of nose wheel steering

13. Tire failure, any tire

14. Gyro failures
    a. a complete loss of any single sensor output*
    b. ramping sensor output
    c. biased sensor output

15. Accelerometer failures
    a. a complete loss of any single sensor output*
    b. ramping sensor output
    c. biased sensor output

16. Radar altimeter failures
    a. a complete loss of all sensor outputs*
    b. ramping sensor output
    c. biased sensor output

17. VOR/ILS failures
    a. a complete loss of all sensor outputs*
    b. ramping sensor output
    c. biased sensor output

18. DME failures
    a. a complete loss of all sensor outputs*
    b. ramping sensor output
    c. biased sensor output

19. Marker beacon failures
    a. a complete loss of all sensor outputs*
    b. ramping sensor output
    c. biased sensor output

20. Air data computer failures
    a. a complete loss of any combination of sensor outputs*
    b. ramping sensor output
    c. biased sensor output
    d. alpha vane failure
    e. pitot tube failure
    f. static vent failure
    g. temperature probe failure

21. Attitude Heading Reference System failures
    a. a complete loss of all sensor outputs*
    b. ramping sensor output
    c. biased sensor output

22. Inertial Reference Unit failures
    a. a complete loss of all sensor outputs*
    b. ramping sensor output
    c. biased sensor output

23. Engine sensor failures
    a. a complete loss of any single sensor output*
    b. ramping sensor output
    c. biased sensor output

24. Automatic Direction Finding failures
    a. a complete loss of all sensor outputs*
    b. ramping sensor output
    c. biased sensor output

25. Flight control surface sensor failures
    a. a complete loss of any single sensor output*
    b. ramping sensor output
    c. biased sensor output

26. Gear sensor failed: complete loss of any single sensor output*

27. Ram air temperature probe failures
    a. a complete loss of any single sensor output*
    b. ramping sensor output
    c. biased sensor output

28. Fail validity bit on any sensor that has one

29. Engine Sync system failures
    a. fail to maximum value
    b. fail to minimum value
    c. fail to zero

* This includes failure of a sensor output signal at some selected destinations but not at others.

APPENDIX D

MFD and HUD Data

Head-Up Display - Primary Flight Data

- Attitude
- Altitude
- Airspeed/Mach No
- Vertical Speed
- Heading
- Flight Path Vector
- Flight Director
- Flight Mode Annunciation

Multi-Functional Displays

Primary Flight Display/Vertical Situation Display (compatible with the HUD)

- Attitude
- Altitude
- Airspeed/Mach No
- Vertical Speed
- Heading
- Lateral/Vertical Deviation
- G Levels
- Flight Mode Annunciation
- Flight Director
- Performance Limits

Navigation Display/Horizontal Situation Display

- Map
  - Flight Plan Waypoints
  - Background Data
  - Inset CDI
  - Weather/Beacon

- Compass
  - Radio Nav-Bearing Device

- Chart
  - Flight Plan Review

Plan Position Indicator (PPI)

- Station Keeping
  - SKE PPI
  - RAW SKE Deviations
  - SKE Annunciations

- Radar
  - Weather
  - Beacon

Engine

- Normal
  - EPR
  - Fuel Used
  - Thrust Reverser

- Thrust Limit
- Thrust Select
- Fuel Flow Totaliser

- Expanded
  - EPR
  - N2
  - Fuel Flow
  - EGT
  - N1

- Secondary
  - Oil Pressure, Temp, Qty

Configuration/Flight Control Display

- Elevator Position
- Stabiliser Trim
- Rudder Position and Trim
- Aileron Position and Trim
- Flap Position and Index
- Slat Position
- Spoiler Position
- Direct Lift Control
- Thrust Reverser
- Landing Gear Position

APPENDIX E

References

1. Douglas Aircraft Corporation report, "Preliminary Trade Study, C-17 Flight Deck, Instruments, Controls & Displays", 16 November 1984.

2. Douglas Aircraft Company Report C-17-PDR-006FD, "C-17 Preliminary Design Review Meeting Minutes, Flight Deck and Accommodations", March 1985.

3. ASD/YCES briefing, "C-17A HUD Status Briefing to ASD/AF", 5 September 1985.

4. Douglas Aircraft Company informal briefing, "Alternate Arrangements", October 1987.

5. USAF/McDonnell Douglas C-17 Technical Description, 1988.

6. Airlift for the 21st Century, a McDonnell Douglas pamphlet, April 1989.

7. Douglas Aircraft Company informal briefing, "Man-In-The-Loop Simulator", 7 June 1989.

8. C-17 Advancing Airlifter Avionics: Technical Description, a McDonnell Douglas pamphlet, July 1989.

9. Douglas Aircraft Corporation report MDC K4685, "System Requirements Specification for the C-17A Flight Hardware Simulator (FHS)", 6 December 1989.

Figure 1 Current C-17 Cockpit

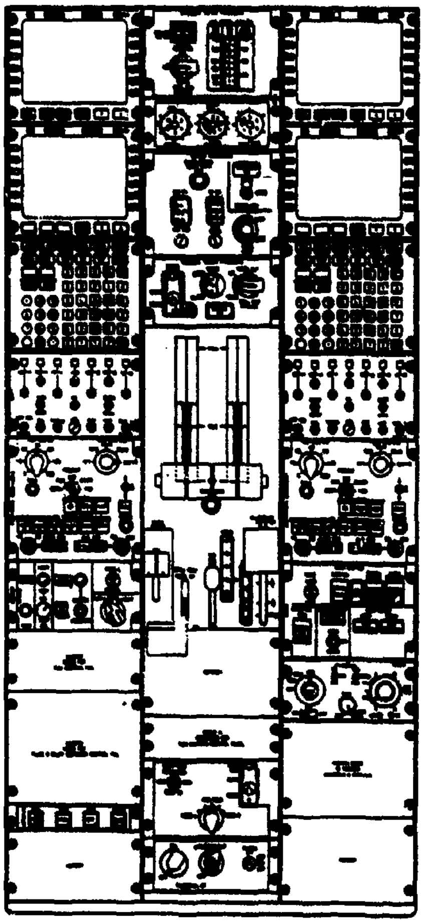

Figure 2 Current C-17 Center Console

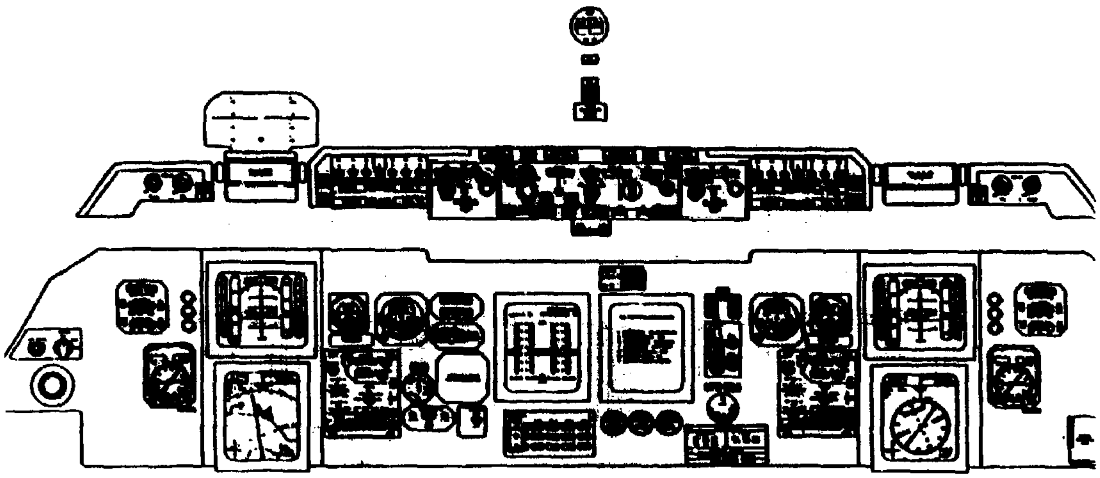

Figure 3 C-X Proposal Arrangement

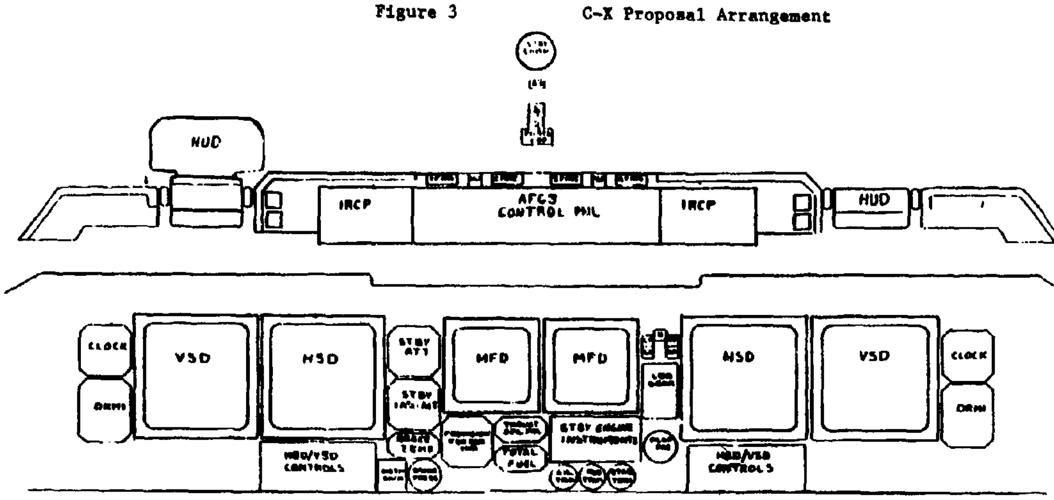

Figure 4 2D-2B-2D Arrangement

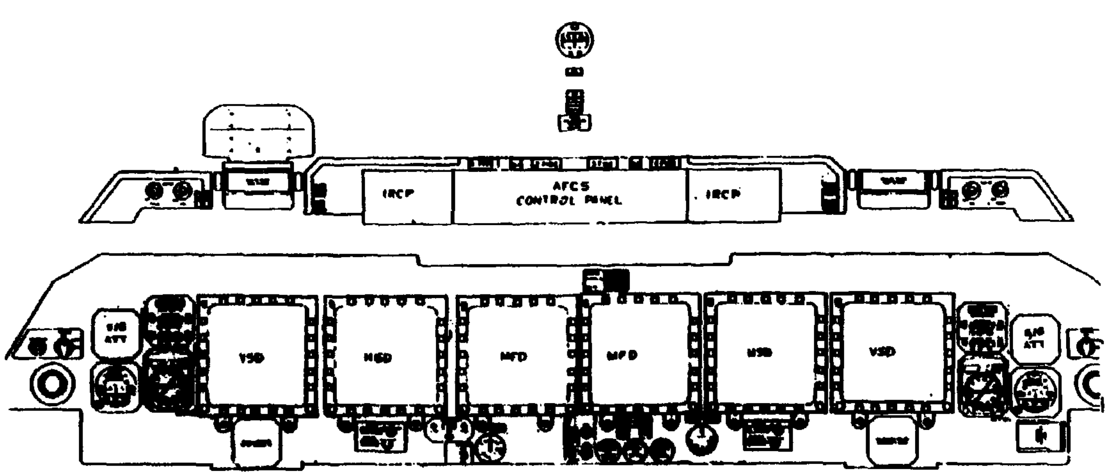

Figure 5 6D Arrangement

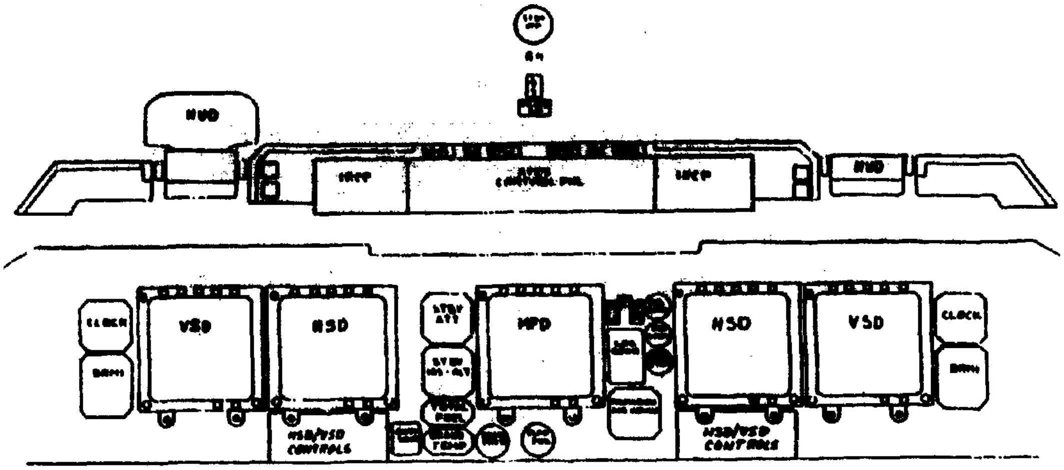

Figure 6 5D Arrangement

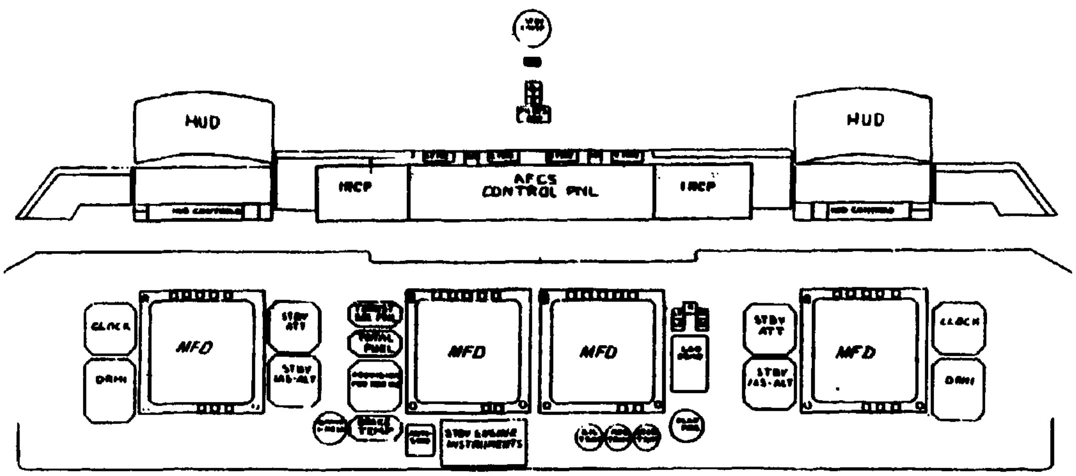

Figure 7 1-2-1D Arrangement

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AIRCREW FATIGUE COUNTERMEASURES

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SUMMARY. Since the earliest days of aviation, there have been aircraft accidents (now referred to as "flight mishaps"). In earlier times, mechanical malfunctions were blamed for the greater number of mishaps. Engineering and technological advances, however, have since lowered the likelihood of "machine-induced" mishaps. Now, the "man" part of the equation (in a chain of events leading to a mishap) is far more likely to be the primary cause. (17:1) Thus, as aircraft are made more durable, reliable, and better able to sustain increased workloads, the humans who operate them must find ways to adapt or cope with the greater demands which result from improved machine capability. The bottom line question for today surfaces as: What causes crewmembers to commit errors in judgment, performance, or perception, and how might the influences of such causes be reduced? Progress in the field of "Human Factors" (HF) analysis has revealed some solutions while advancing the fundamental goal of flight safety--mishap prevention. This paper is intended to clarify and summarize the impact of HF studies on mishap prevention and show how aircrew fatigue is a common denominator among HF elements. Accepted techniques for combating and coping with fatigue are listed. Finally, recommendations on how to maintain operational awareness of aircrew fatigue considerations are proposed. (25) *Flight Crews, *Fatigue (Physiology), *Stress (Physiology).

AIRCRAFT MISHAPS. Great strides have been made towards flight safety's mishap prevention goal. As the first step in the process of reducing the likelihood of recurrence, causes must be identified. Actual aircraft mishaps and near mishaps provide investigators with opportunities to study possible causes. Safety professionals search out not only what happened, but try to focus more on why a mishap occurred. (1:8) Mishap statistics also offer clues which help identify areas of greater mishap potential. For example, analysis indicates the majority of jet aircraft accidents occur during the approach or landing phases of flight. (25:18) Such evidence certainly justifies greater attention to ensuring optimal crew performance during initial and final stages of flight.

Mishap Causes: Federal Aviation Administration (FAA) mishap studies show a common factor: human failing rather than mechanical malfunction is the prevalent cause of flight mishaps. (14:2) Though mishaps may be attributable to design, maintenance, air traffic control, sabotage, or "acts of God," the crew is often a key element. (25:181) Since aircraft safety design engineers have nearly worked themselves out of a job by resolving the machine-caused part of the problem, crew-caused mishaps dominate all other types despite increased priority given cockpit resource management programs. (17:11; 11:21) Complacency, overconfidence, or inattention are a few factors which now tend to go together in building the HF picture. (19:11) The applied technology of human performance, or "ergonomics," receives increased levels of attention, but the riddle remains unsolved. (17:1) Pinning down an HF error is a mammoth proposition for any mishap investigation team. Nonetheless, up to 80 percent of all aircraft mishap studies attribute HF as "casual." (17:1; 12:14) Recent studies suggest many more mishaps could be blamed on HF if the reason for the "undetermined cause" category of mishaps could be substantiated. (16:14)

Human Factors Studies: Flight Safety professionals continue to look at HF more closely now as they attempt to unravel the mystery of what causes people to crash perfectly good aircraft. HF is defined as "the study of physical, physiological, psychological, psychosocial, and pathological limitations of man as he interfaces with his environment." (16:13) Simply stated, HF is a broad discipline which attempts to account for mishap causes not directly attributable to hardware failure. The investigative model used in HF analysis includes the following basic categories: environmental, equipment design, workload, operational, behavioral, and medical. Within the medical category fall the following elements: general health, sensory acuity, drug/alcohol ingestion, and fatigue. (2:2) Considering the increased attention given HF in mishap investigation, HF should also receive increased emphasis in mishap prevention. Aviation professionals are calling for new methods to prevent fixation or distractions which can monopolize the thinking processes of crewmembers who are supposedly trained to avoid such traps. (25:181) FAA safety specialists acknowledge they cannot make flight rules for every situation, and they stress that pilots have a moral responsibility to operate in the safest way possible by considering personal limitations, including fatigue. (14:4) Fatigue among aviators often occurs due to stress associated with "circadian rhythms."

Effects of Circadian Rhythms. Circadian rhythm is a term applied to the body's normal day/night cycle. Body rhythm (circadian) desynchronization has long been acknowledged to have a profound effect on motivation and performance. (12:15) The exact mechanism of circadians is not fully understood, but the effects have been shown to be extremely disruptive in terms of how a person "feels" when the normal activity cycle is interrupted. (9:53) The daily sleep/wake cycle for most people is longer than 24 hours, usually by 1 to 3 hours. The average cycle is 25.2 hours. Thus, greater fatigue occurs when traveling

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in an easterly direction than traveling west because the day is "compressed" (west to east flight) as opposed to being "stretched" (east to west flight). (22:242; 5:2) Aircrews are particularly susceptible to the effects of circadians, and even the most motivated professionals have fallen victim to that elusive mental mechanism which can temporarily numb the brain into inactivity at critical times. (25:181) We know staying at a particular destination long enough eventually permits resetting of the biological clock, or "entrainment," at the rate of about 1 hour per day (1 day for each time zone crossed. (5:2) Unfortunately, aircrew schedules rarely permit entrainment to occur at en route stops. As the body tries to adapt to the stress of a circadian shift, sleep becomes more difficult and less restful. Less restful sleep induces fatigue. (23:5) In fact, any attempt to modify regular body rhythms induces fatigue. (13:140) Long periods of wakefulness cause disorientation along with mental and physical exhaustion. (18:E11) Furthermore, after a period of little or no sleep, it takes two normal rest periods to regain normal levels of alertness. (8:14) Nevertheless, a frustrating fact remains: a person can't force himself to sleep when he isn't sleepy. (5:2)

The FAA acknowledges a lowered alertness level for crews on today's aircraft when subjected to rapid time zone displacement (jet lag) due to traveling in easterly or westerly directions. During these periods of "dullness," there is a measurable lowering of body temperature, and such low points normally occur from about 0300 to 0500 hours in the morning. (5:1) Medical opinion varies regarding a precise range for circadian low periods in the morning hours. The most inclusive range spans the hours between 0200 hours and 0600 hours, with 0400 hours being the very lowest point. (21:3; 12:14; 8:13) Later, beginning about 0800 hours, mental performance and memory seem to improve until a peak at about 1600 hours. (19:7; 8:13)

<u>FATIGUE</u>. By its very nature, aviation is conducive to fatigue. Yet, the effects of fatigue are insidious. Since it cannot be unequivocally measured or defined, fatigue does not have a specific scientific meaning. (15:2) Being so difficult to quantify, it must normally be self-recognized. Rather than depending upon the amount of work performed, it calls for subjective judgment about how an individual feels. But fatigue's effects vary among individuals and may not even be apparent to a pilot or his crew. (15:28; 24:37) Some aviators think they can fly for long hours without adequate rest, although they are probably not aware of their own diminished performance levels. They may be able to remain awake under such circumstances, but they are generally more accident-prone and less efficient. (7:7) Military pilots on long-haul transmeridian flights are especially susceptible to the effects of sleep deprivation. (15:172) Thus, it is reasonable to assume that performance degrades as a result of fatigue. (9:56) Specifically, fatigue slows reaction times and causes errors due to inattention. (20:6)

<u>Characteristics of Fatigue</u>. There are two categories of fatigue: acute and chronic. Acute fatigue, the more common type, is caused by excessive physical or mental activity associated with short-term stress. Though serious, a good night's sleep usually resolves acute fatigue. Chronic fatigue results from prolonged exposure to stress and causes symptoms including insomnia and forgetfulness. Although not as severe as acute fatigue, chronic fatigue is not as easily relieved. (24:37) Some of the psychomotor changes associated with fatigue include: disruption of timing and perceptual field of vision; decreased memory, attention span, cooperativeness, and communication skill; and increased reaction times, anxiety, irritability, and error rates. (19:6; 23:5) Industry research shows fatigue can cause inattention, perseveration of ideas, confusion, and anxiety--any of which can degrade cockpit interaction. (4:93) Recent FAA analysis has shown the three major fatiguing factors for crews are number of time zones traveled, multiple layovers in close sequence, and 24-hour layovers after a night arrival. Although any one of these factors can be accommodated by a crewmember during a layover, the presence of two or more begins to strain physiologic recovery. Should all three factors be present during a single mission, fatigue can have a dangerous effect on crew performance. Other "moderate" factors which may contribute to mission fatigue include flight in an easterly direction, multiple transits, day sleep, and missions in excess of seven days. (22:244) Accumulation of other operational factors (e.g., departure delays, aircraft malfunctions, air traffic, and meteorologic conditions) also contribute to fatigue. (21:3) So, even though a pilot may be provided 10 hours rest time, if it is during a period out of synch with reference to his body rhythms, he may not realize the full benefit intended prior to beginning flight duties. Furthermore, his efficiency could be further reduced to dangerously low levels if he must fly during his minimum performance rhythm period. (3:53)

<u>Fatigue--A Common Denominator</u>. Pilots are routinely expected to perform complex tasks demanding physical well-being and mental alertness. As the most important part of the weapon system, the pilot often becomes the weakest link in the chain if not in good health. (7:8) Fatigue is consistently listed among physical and physiological factors impacting a given HF mishap. (1:7) Since noise and vibration increase fatigue, the flight environment itself is fatiguing. In addition to causing increased inattention, emotional stress also promotes fatigue. Even before a pilot actually feels the first signs of fatigue, "performance decay" and poor judgment become noticeable. (19:7) Inherent human limitations in monitoring automated systems, further impaired by fatigue or circadian disrhythmia, have led to a number of mishaps or near mishaps. (17:4) In fact, there have been aircraft mishaps where HF investigation has shown the cause was solely or partially due to pilot fatigue. (15:4)

Professional pilot reports indicate decrements in flight performance and effective crew interactions are related to the time of day (i.e., circadians). Further, these decrements are more severe during the final phases of flight, when fatigue would be expected to be greater. (4:93) In near mishaps, pilot disorientation has even occurred during final approach for landing when a high degree of pilot fatigue was present. (10:23) Because interruptions in normal sleep patterns are considered the primary cause of fatigue, the importance of disrupted sleep as a causative factor in mishaps may actually be underestimated. (15:173; 21:2) In short, most HF elements can either lead to, or result from, fatigue. At the very least, fatigue makes aircrews more susceptible to other HF elements. Because fatigue is now commonly acknowledged as a major problem in the cockpit, FAA human factors research workshops have called for more in-depth study into the effects of fatigue on stress and flight deck operations. (4:93)

Reducing the Effects of Fatigue. The individual crewmember has the greatest influence on his own physical well being and can, therefore, affect his own resistance and adaptability to fatigue. Since man is designed to operate better in daytime than at night and geared for regular patterns of rest and activity, fatigue can't be completely eliminated. (23:6) Certain routine practices can aid in fatigue prevention. Naturally, a regular work-rest schedule plays a major role. Other factors include regular physical conditioning programs, healthy eating (moderate proportions of high protein/low carbohydrate foods are better than simple sugar foods), and moderation in alcohol consumption and smoking. During flight, drinking plenty of water (about one glass per hour is recommended) as well as stretching and flexing exercises will help ward off fatigue. (6:15; 24:38) The FAA also recommends remaining mentally active during long flights by making frequent radio, navigation, and systems checks. (20:6)

Operational managers play a significant role in the fatigue prevention formula. Without a reminder about physiologic guidelines, suggest commercial aviation experts, schedulers may consider the crew as an inanimate component in a system which is primarily geared towards mission accomplishment. (22:241) Aviation safety professionals recommend mission schedules which avoid multiple night flights, 24-hour layovers, and multiple time zone crossings whenever possible. (21:4) Crews need to know their own physiologic indices for a given flight profile and must judiciously plan their rest periods whenever mission schedules jeopardize optimal work cycles. (22:247) Finally, the Flight Safety Foundation stresses that pilots who report excessive fatigue should not be punished for refusing to fly. (21:4)

RECOMMENDATIONS. The above study identifies fatigue as a likely common denominator in the HF arena. Unfortunately, fatigue is difficult to define or measure, and even more difficult to remedy. How a given crewmember "feels" physically and emotionally is possibly the key element in that crewmember's HF risk profile. While empirical evidence on the significance of fatigue in mishaps may be lacking at present, most safety experts agree fatigue is a factor in many mishaps. From the information available today, two fundamental conclusions about fatigue can be derived: (1) Stresses associated with HF considerations commonly lead to aircrew fatigue; and (2) Aircrew fatigue frequently leads to or generates many of the HF elements which figure so prominently in mishaps. So, fatigue may either lead to or result from the stresses considered in the HF arena. Therefore, fatigue may be considered a "common denominator," or a linking factor, in HF. This conclusion is particularly relevant for MAC aircrews, since they are exposed to some of the most fatigue-inducing flight duty days in aviation. Ironically, fatigue among Military Airlift Command (MAC) aircrews is possibly more controllable than operations managers will admit. The most common reason for constructing fatigue-inducing mission schedules is "user requirements" (i.e., the supported organization prefers to move or receive goods at the particular time of day they have requested). Another reason is "base operating hours." Such "support driven" rationales are understandable but should not justify routinely forcing flight safety to take a back seat for user convenience. The "mindset" orientation of aircrews regarding a given schedule may offer another clue to a rather insidious "fatigue trap." Crewmembers often focus their attention on relatively unimportant mission schedule details (such as time for shopping and amount of free time available) which actually detract from optimal crew rest opportunity. As discussed earlier, the duration of crew rest periods is just as important as timing of actual rest relative to the individual's circadian rhythm (i.e., his "home station" biological clock).

In-flight periods when critical tasks (i.e., take-off and landing) must be accomplished deserve much greater focus during schedule development and mission execution. Schedulers and crews should work to align such periods to coincide with hours of peak performance (as suggested by circadian rhythm). Practical application of HF principles is the greatest obstacle to real progress in preventing aviation mishaps caused by human factors related issues. The following proposal would serve as an initial step to apply HF principles: For each daily mission profile, operations sections should provide "circadian daily planner" mission schedule charts to highight critical/demanding mission tasks as well as low task performance periods (see Tables 1, 2, and 3). The "home station" time between 0800 hours and 1600 hours is shaded on each mission schedule to call attention to the optimal circadian performance periods. Likewise, the "low ebb" period between 0200 hours and 0600 hours is shaded to alert schedulers and crews to that suboptimal circadian period. Critical mission tasks (i.e., take-offs and landings) can be tracked on this planning form, as optimal periods for work and rest are readily identified. The highlighted information can alert schedulers and crews to optimal periods for critical tasks or rest and offer a reminder to make adjustments whenever possible. Although this is a rather simplistic approach to fatigue reduction, it takes a first practical step towards circadian awareness. Such a "picture" of crew tasks relative to circadian cycle and fatigue would offer schedulers, crewmembers, and operations management a useful tool for massaging the mission schedule for a given crew.

The most fragile element in the flight operations system is the aircrew. Granted, aircrews are a highly adaptive group, but their adaptability has limitations which can lead to catastrophic consequences. Aircrews make mistakes, and a fatigued crew is even more likely to err. A fatigued crew can easily become the weakest link in an unfortunate chain of events, so reducing fatigue warrants extra efforts by all aviation professionals. Although most aviators and managers are intuitively aware of crewmember fatigue limitations, no structured method for managing the problem currently exists. Thus, it is incumbent upon all operations or support people to make an effort to manage aircrew fatigue in any manner and at every opportunity available. Implementing any system towards the goal of reducing aircrew fatigue's impact on safety would highlight the importance of aircrew fatigue abatement, and thereby serve as a point of departure for further improvements.

Table 1

HYPOTHETICAL MISSION PROFILES

		Low Fatigue Schedule (See Table 2)			High Fatigue Schedule (See Table 3)		
EVENT	PLACE	GMT	LOCAL	HOME	GMT	LOCAL	HOME
Show	CHS	0800	0300	0300	1900	1400	1400
T.O.	CHS	1015	0515	0515	2115	1615	1615
LND	DOV	1130	0630	0630	2230	1730	1730
T.O.	DOV	1445	0945	0945	0145	2045	2045
LND	RMS	2215	2315	1715	0915	1015	0415
---Crew Rest							
SHOW	RMS	1330	1430	0830	0030	0130	1930
T.O.	RMS	1545	1645	1045	0245	0345	2145
LND	TJZ	1745	1845	1245	0445	0545	2345
T.O.	TJZ	2100	2200	1600	0800	0900	0300
LND	ATH	0000	0200	1900	1100	1300	0600
---Crew Rest							
SHOW	ATH	1700	1900	1200	0400	0600	2300
T.O.	ATH	1915	2115	1415	0615	0815	0115
LND	RMS	2215	2315	1715	0915	1015	0415
---Crew Rest							
SHOW	RMS	1515	1615	1015	0215	0315	2115
T.O.	RMS	1730	1830	1230	0430	0530	2330
LND	CHS	0130	2030	2030	1230	0730	0730

Notes:
CHS = Charleston, South Carolina
DOV = Dover, Delaware
RMS = Ramstein, Germany
TJZ = Torrejon, Spain
ATH = Athens, Greece

The mission profiles are identical--same en route and ground times. The Low Fatigue Schedule has mission "start time" shifted by 13 hours in consideration of circadian rhythms.

DISCLAIMER

This research report represents the views of the author and does not necessarily reflect the official views of the Department of Defense or the United States Air Force.

TABLE 2. CIRCADIAN DAILY PLANNER - Low Fatigue Schedule (Hypothetical)

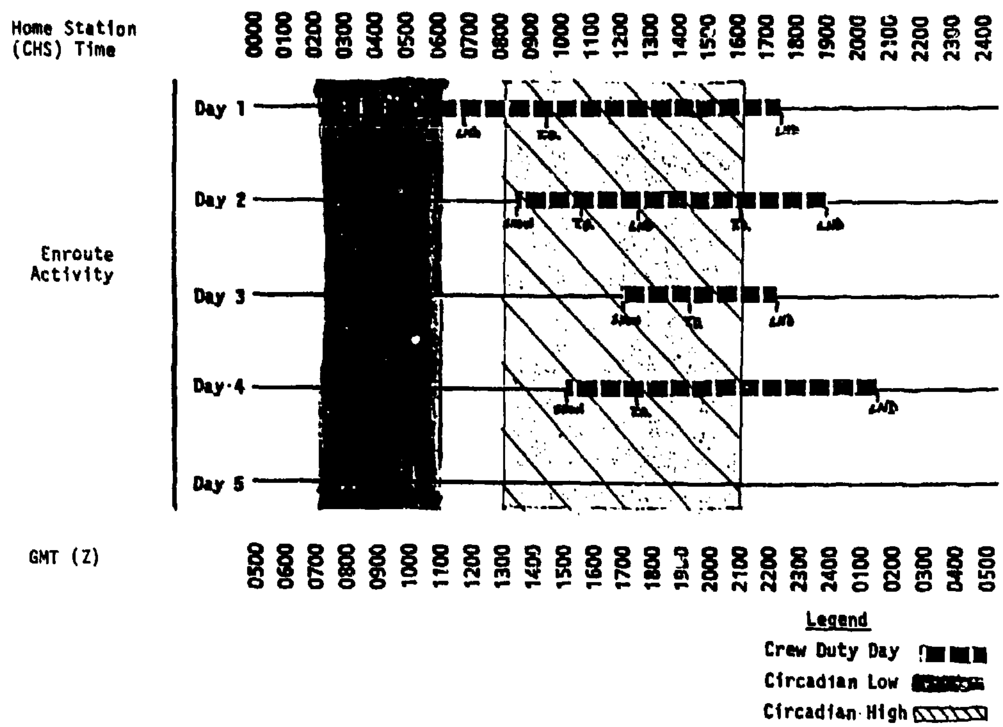
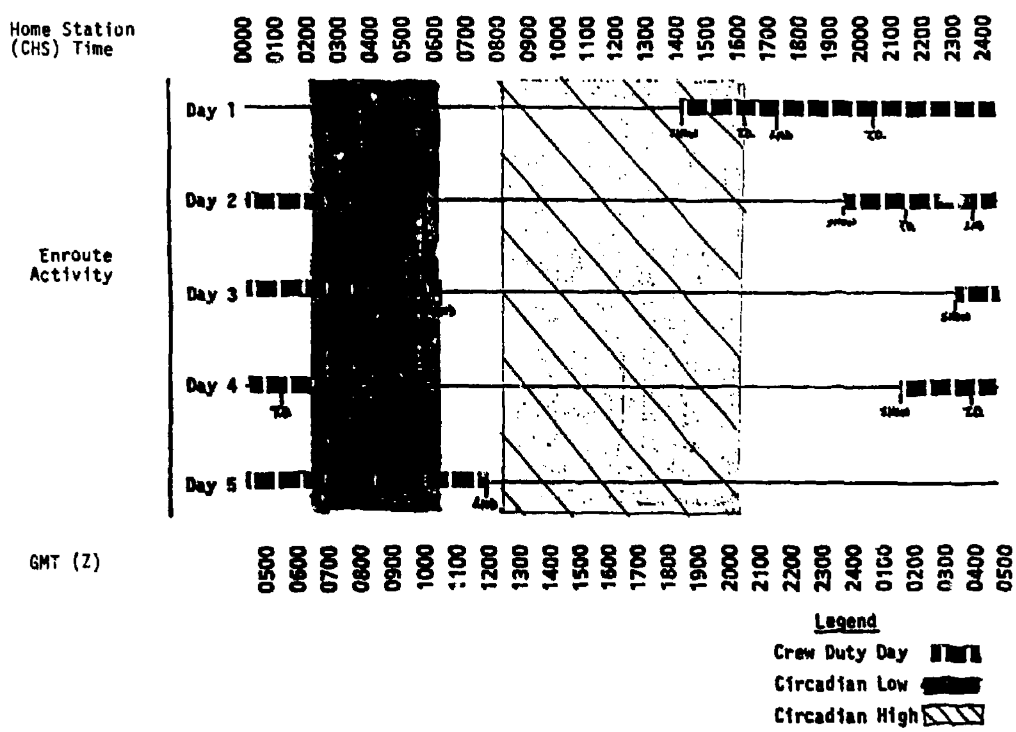


TABLE 3. CIRCADIAN DAILY PLANNER - High Fatigue Schedule (Hypothetical)



BIBLIOGRAPHY

1. Bailey, Maj T.A., Canadian Forces, "Cause Factor Determination and Aircraft Accident Investigation in the Canadian Forces," Flight Comment, No. 2, 1988, pp. 6, 8.

2. Barthelmess, Sharon, "Human Performance Factors in Accident Investigation," Flight Safety Digest, January 1985, pp. 1-8.

3. Chapman, Robert P., Pilot Fatigue - Deadly Cover-Up, New York, Exposition Press, 1982, p. 53.

4. Cockpit Human Factors Research Plan, Aviation Behavioral Technology Program, Federal Aviation Administration, Washington DC, January 1985, p. 93.

5. "Daily Body Rhythms and Flight Safety," Accident Prevention Program, Federal Aviation Administration, U.S. Department of Transportation, Washington DC, FAA-P-8740-46.

6. Deisel, Capt Donald A., "Combating Fatigue," The MAC Flyer, November 1986, pp. 14-15.

7. Dobie, Gp Capt T.G., Royal Air Force, Aeromedical Handbook for Aircrew, March 1972, pp. 7-8.

8. "Fatigue and Performance," Flight Safety Focus, Vol 3, April 1988, pp. 13-16.

9. Gabriel, Dr Richard F., "A Review of Some Universal Psychological Characteristics Related to Human Error," McDonnell Douglas Corporation paper 6401, presented to International Air Transport Association, 20th Meeting, November 1975.

10. -----. "Some Potential Errors in Human Information Processing During Approach and Landing," McDonnell Douglas Corporation paper 6587, presented to Air Line Pilots Association, International Symposium on Human Factors Emphasizing Human Performance, Workload, and Communications, February 1977.

11. Gallimore, P.L. and Lautman, L.G., "Control of the Crew-Caused Accident," Airliner, Boeing Commercial Airplane Company, April-June 1987, pp. 21-25.

12. Hawkins, Capt Frank, "Checklists and the Human Factor," The MAC Flyer, September 1987, pp. 14-15.

13. Henry, James P., Biomedical Aspects of Space Flight, New York, Holt, Rinehart and Winston, Inc., 1966, pp. 76, 135, 140.

14. "Human Behavior, The No. 1 Cause of Accidents," Accident Prevention Program, Federal Aviation Administration, U.S. Department of Transportation, Washington DC, FAA-P-8740-38.

15. Jensen, T.G., "Fatigue Factors on Two Man Crew," Flight Safety Focus, Vol 8, December 1987, pp. 2-10.

16. Lee, Maj Kent, USAF, "Human Factors: A Tough Nut to Crack," The MAC Flyer, August 1988, pp. 13-15.

17. Lee, Dr Robert B., "Pilot Performance and Flight Safety," Flight Safety, Vol 38, March-April 1988, pp. 1-8.

18. Man's Body, The Diagram Group, New York, NY, Bantam Books, 1981, p. E11.

19. Markle, "Fatigue," The MAC Flyer, June 1987, pp. 6-7.

20. "Medical Facts for Pilots," Accident Prevention Program, Federal Aviation Administration, U.S. Department of Transportation, Washington DC, FAA-P-8740-41.

21. Mohler, Dr Stanley R., "Modern Concepts of Aircrew Fatigue," Human Factors Bulletin, Flight Safety Foundation, Inc, Arlington VA, May/Aug 1981.

22. -----. "Physiological Index as an Aid in Developing Airline Pilot Scheduling Patterns," Aviation, Space, and Environment Medicine, March 1976, pp. 238-247.

23. "Night Flying and Fatigue," TAC Attack, November 1982, pp. 4-6.

24. "On Preventing Fatigue," Business Aviation Safety, Vol 3, 1987, pp. 36-68.

25. Shu, J. Shang, "Awareness, A Safety Challenge," The International Journal of Aviation Safety, September 1984, pp. 181-182.

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Aircrew Eye/Respiratory Protection
A Military Airlift Command Perspective

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SUMMARY

This paper summarizes Military Airlift Command's (MACs) and Air Force System Command's (AFSCs) effort to improve aircrew eye/respiratory protection (AERP) in the chemical defense environment. It discusses the significant effort to plan the concept, manage the acquisition, design the system, test the system, and redesign the system to meet MAC's requirements. MAC's mission to conduct and support operations remains the same during war and peacetime and despite the presence of chemical agents. We need an effective AERP system to support our worldwide operations. Our ongoing test effort has uncovered important problems and challenges to overcome. However, after hundreds of ground and over 50 flight test hours in the MAC mission environment, solutions are on the way. We now have even more challenges, but the numerous hurdles already cleared have prepared and encouraged us to proceed.

(25) * Eye, * Respiratory System; * Protective equipment, * Chemical agents

INTRODUCTION

The purpose of the AERP system is to provide aircrews protection from exposure to chemical agents allowing them the capability to accomplish assigned missions worldwide. Current aircrew above-the-shoulder chemical warfare defense equipment provides only limited protection, does not have valsalva capability, is not compatible with some other systems (e.g., night vision goggles), and causes physiological impairment which seriously degrades mission accomplishment. Therefore, enhanced AERP is the number one USAF chemical warfare defense research and development priority.

MAC DEPLOYMENT CONCEPT

In the worst case scenario, military confrontations could escalate to use of chemical munitions concurrently with conventional weaponry. Chemical Warfare Defense (CWD) plans must ensure protection of aircrew, passengers, and cargo to allow for continued air operations. During periods of increased tension (as directed by MAC command and control) aircrews will ensure their protective equipment is loaded on board their aircraft prior to departure from the continental United States or overseas operating locations. Limited quantities of aircrew CWD protective equipment are stored at selected overseas locations to facilitate issue to en route aircrews during buildup of tensions/hostilities.

The AERP system and associated protective equipment will be donned and worn whenever the presence of chemical agents is known or suspected. Aircrews recovering to bases located within a Chemical Threat Area (CTA) will comply with local contamination control procedures. If aircraft recovery occurs at locations outside the CTA, aircrews will continue to wear protective equipment until they are processed through a contamination control line. Aircrews will follow similar CWD protective procedures during subsequent aircraft missions which require flight through known or suspected chemical threat environments.

IMPROVED AERP BACKGROUND

USAF War and Mobilization Plan, Vol I (USAF WMP-1), Annex J, requires training and equipping of all units located within, or tasked for deployment to, chemical threat areas (CTAs) to ensure their ability to operate in a chemical warfare environment. Recognizing the immediate nature of the chemical warfare threat in the mid 1970s, HQ USAF directed procurement of an off-the-shelf MBU-13P smoke mask based protection system for aircrews. In 1977, HQ USAF further directed an operational evaluation of the MBU-13P AERP to determine its limitations. Simultaneously the Aeronautical Systems Division (ASD) began a research and development program to find an improved AERP. The emphasis was on minimum aircraft modification and minimal design work. ASD evaluation concluded that development of two AERP systems, integrating characteristics of several off-the-shelf candidates, would meet the total Air Force requirement. The selected candidates were the Tactical Aircrew Eye Respiratory System (TAERS) for fighters and the Protective Integrated Hood/Mask (PIHM) for all other aircraft. The large number of aircraft and associated missions have been reduced to eight aircraft categories. These categories were selected based on similarities of aircraft and/or missions.

AIRCRAFT CATEGORY	REPRESENTATIVE AIRCRAFT	AERP SYSTEM
Fighter/Attack	F-16B/C/D	TEARS
Observation	OV-10A	PIHM
Strategic Bomber	B-52G	PIHM
C-130 and related	C-130E, AC-130H	PIHM

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C-135 and related	KC-135A	PIHM
Operational Support	C-9A	PIHM
Helicopter	MH-53J	PIHM
Other	B-1B	PIHM

Aircraft shown will be used to conduct Development Test and Evaluation (DT&E) and Initial Operational Test and Evaluation (IOT&E) for all aircraft of that category.

If the test results prove successful and the respective aircraft's command approves, further modification kit design engineering will be accomplished for each individual aircraft of that category. The AERP procurement and modification action will then be accomplished through each aircraft's respective Air Logistics Center (ALC). The following list shows the numerous aircraft under each category.

C-130 and related

C-130A
C-130B
C-130E
C-130H
EC-130E
EC-130H
AC-130A
AC-130H
AC-130U
HC-130H
HC-130N
HC-130P
MC-130E
MC-130H
WC-130E
WC-130H
LC-130H

Fighter/Attack

F-111A
F-111D
F-111E
F-111F
FB-111A
EF-111A
A-7D
A-7K
A-10A
F-4C
F-4D
F-4E
F-4G
RF-4C
F-15A
F-15B
F-15C
F-15D
F-16C
F-16D

C-135 and related

E-3A
E-3B
E-3C
E-4B
EC-135A
EC-135C
EC-135G
EC-135H
EC-135J
EC-135K
EC-135L
EC-135P
EC-135Y
KC-135A
KC-135D
KC-135E
KC-135Q
KC-135R
RC-135S
RC-135T
RC-135U
RC-135V
RC-135W
C-135A
C-135E
NKC-135A
WC-135B
KC-10A
C-5A
C-5B
C-17A
C-141B

Other

B-1B

Helicopter

TH-1F
UH-1F
MH-1H
UH-1P
CH-3E
CH-53C
MH-3E
MH-53B
MH-53C
MH-53J
MH-60G
UN-60A
UN-1N

Operational Support

C-9A
C-12A
C-12D
C-12F
C-12J
C-20A
C-21A
C-22A
C-22B
C-23A
C-26A

Strategic Bomber

B-52G
B-52H

Observation

O-2A
OA-37B

SYSTEM DESCRIPTION

The AERP candidate selected to replace current MAC aircrew eye/respiratory protection is the Protective Integrated Hood/Mask (PIHM), and under-the-helmet system. This system provides eye protection, filtered air/oxygen, and protective head and neck covering for aircrew personnel. The PIHM is compatible with current below-the-neck ensemble, chemical warfare defense equipment, and MAC aircraft crew stations and escape systems.

The PIHM requires aircraft modification to provide blown air for the breathing and ventilation. The modification kit, consisting of a blower bracket and a 28 VDC electrical plug (with associated wiring) for each crew position, will be installed by MAC personnel (aircraft electricians, structural maintenance, and crew chiefs) with contractor training and supervision. See annex for further details.

MAC TEST CONCEPT

Test Planning and Execution Challenges

The MAC test effort is directed toward qualification, man-rating, and evaluation of the operational effectiveness and suitability of the PIHM using MAC C-130E, AC-130H, MH-53J, and C-9A aircraft. These aircraft were selected to conduct DT&E and IOT&E with the PIHM system for that category of aircraft (C-130, helicopter, and operational support, respectively). MAC active duty units at Pope AFB NC, Hurlburt Fld FL, and Scott AFB IL will provide the test bed aircraft.

MAC ideally receives a newly developed system from the implementing command after it has been fully tested and qualified. But in this case, AFSC did not have the resources to flight test the PIHM system. As part of a MAC-AFSC joint effort, we developed a plan to qualify the PIHM using MAC aircrews and aircraft. After extensive laboratory and ground testing, we flew our operational missions in this unproven system under AFSC test direction. In essence, our operational aircrews are performing as test pilots. The greatest challenge is releasing operational resources for test purposes. The day-to-day MAC mission is first and foremost priority at our operational units, but the requirement to flight test the improved AERP system is also a priority. As testing proceeds, this sort of dilemma is still prevalent and continues to be a challenge to MAC aircrew members as well as for our planners.

Flight testing consists of flying normal MAC mission profiles with aircrew members wearing the PIHM. Prior to the first test flight, aircrew training and ground preflight inspections will be accomplished using the system and the complete below-the-shoulder aircrew chemical ensemble. During the qualifying flights, only half of the crew will be wearing the PIHM. But during operational flight testing the entire crew will wear the system, with safety observers, to test our aircrews and to ensure our operational concept is a sound one.

Critical Operational Issues

To promote test and program integrity, as well as ensure valid conclusions could be drawn, several critical operational issues were developed. Key among these is the issue of mission degradation, the capability of aircrews to protect themselves from effects of the chemical environment without adversely affecting mission effectiveness or aircrew safety. In the case of the PIHM, we need to determine whether or not it is compatible with other life support, cockpit, and individual equipment. We also need to know if the PIHM degrades aircrew egress? Other operational issues are as follows:

* Can the PIHM system and its support equipment be operated and maintained by USAF personnel?

* Is the PIHM system maintainable, reliable, and available?

* Is the PIHM system's technical documentation adequate and understandable by USAF personnel?

* Are unique tools or support equipment necessary to test or maintain the PIHM system?

* Does operating the PIHM system create electromagnetic interference with other electrically-powered aircraft systems?

* Is aircraft-generated 28V DC power available?

The bottom line question is "will the PIHM system help MAC perform its mission?"

Problem Areas

MAC recently tested the C-130E at Pope AFB NC over the last year and the many long hours of test planning and execution yielded some very interesting findings. These following findings warrant further evaluation of the PIHM system.

* Difficulty in attaching to and removing blowers from their mounts.
* Navigator blower extension hose restricts movement to windows for airdrop.
* Impossible for strapped-in pilot/copilot to adjust blower intensity.
* No way to safely purge oxygen mask of vomit.
* Trace of ammonia smell present.
* Only one loadmaster bracket position in the cargo compartment.
* Extreme bulkiness of chemical ensemble, flak jacket,survival vest, PIHM, and parachute.
* Loadmaster bracket on flight deck practically inaccessible.
* On low level flight the loadmaster and flight engineer found it easier to breathe by removing the pigtail adapter.
* Slight restriction looking left.
* Ear loop glasses uncomfortable.
* Intercom cord too short and female end too hard to find for connection/ disconnection.

To date a thorough analysis of these problems has not been completed, so by no means can we draw final conclusions. Certainly the data collected shows a need for further evaluating how we intend to perform our mission. Further engineering and testing is needed and scheduled over the next two years, but we are progressing toward viable equipment to protect our aircrews in a chemically contaminated war zone.

CONCLUSIONS

Airlift is crucial to any war effort. Our ability to rapidly project personnel and equipment against the enemy is critical to the outcome. The chemical threat is a fact of life, and our need to defend against that threat requires the use of equipment and procedures which reduce operational efficiency. A toxic chemical environment is among the greatest challenges of our aircrew members since it requires the wear of cumbersome equipment and modification of standard operating procedures. Any advances in equipment or procedures which reduce the impact on mission accomplishment must be pursued if we are to maintain a viable capability to operate in a chemical warfare environment. Personnel must be conditioned to accept the limitations imposed by a chemical scenario and must train to overcome those limitations. The PIHM system will perform its required task, but the degree of effectiveness will be determined by the level of effort we apply to training our aircrews.

LIST OF ABBREVIATIONS

AERP	Aircrew Eye/Respiratory Protection
AFB	Air Force Base
AFSC	Air Force Systems Command
ALC	Air Logistics Center
ASD	Aeronautical Systems Division
CTA	Chemical Threat Areas
CW	Chemical Warfare
CWD	Chemical Warfare Defense
DT&E	Development Test and Evaluation
EPDM	Ethylene-Propylene-Diene-Manomer
EMI	Electromagnetic Interference
HQ USAF	Headquarters United States Air Force
IAW	In Accordance With
IOT&E	Initial Operational Test and Evaluation
MAC	Military Airlift Command
NATO	North Atlantic Treaty Organization
NVG	Night Vision Goggles
OT&E	Operational Test and Evaluation
PIHM	Protective Integrated Hood/Mask
TEARS	Tactical Aircrew Eye Respiratory System
US	United States
USAF	United States Air Force

ANNEX

SYSTEM DESCRIPTION

Protective Integrated Hood/Mask (PIHM) System

The PIHM is an under-the-helmet system which includes a hood assembly with an integral MBU-12/P oronasal mask, a facepiece and headcowl, a C-2 NATO filter and manifold, portable air filter/blower unit, and connecting breathing and ventilation hoses. The hood assembly is designed to interface with USAF aircrew helmets using standard offset bayonet connectors, and is to be worn between the flight suit and the standard chemical defense (CD) inner coverall. The PIHM protects the individual by filtering the breathing air from the aircraft oxygen regulator and pressurizing the head and neck cavity with filtered ventilation air from the blower.

Hood Assembly

The hood assembly is composed to three elements: the personal mask, facepiece, and headcowl assembled to form a protective head and neck cavity. The headcowl is designed to permit easy removal and reuse of the MBU-12/P for resizing, decontamination, or disposal if needed.

Oronasal Mask

The mask is the USAF standard MBU-12/P modified to provide a drinking capability. The standard silicone rubber oxygen hose is replaced by a ethylene-propylene-diene-manomer (EPDM) hose which is liquid agent and ozone resistant. The mask is available in the four standard USAF sizes fitting the 5th through 95th percentile male. It includes a standard aircrew microphone for on board use and connects to a battery powered intercommunication unit for ground communication.

A flexible drinking tube enters the mask cavity through a hollow suspension webbing attachment bolt. It has a connector/check valve to interface with the standard canteen cap. The external drinking tube is formed for storage around the oxygen mask, and the canteen connector is secured in a retainer pocket sewn under the hood chin to protect it from chemical contamination when not in use. The aircrew member drinks through a mouth-manipulated tube inserted inside the mask near the lips. This permits the crew member to vary its location as preferred.

Facepiece

The facepiece is formed by attaching the visor to the head cowl material which is formed to cover the standard mask over the nose cup. The facepiece is secured at the mask suspension webbing attachment points and held in position by standard offset bayonet connectors on the helmet. These connectors provide normal mask adjustments for fit and pressure. A ventilation air hose is routed along the MBU-12/P mask hose and enters the facepiece at the same location. The visor is a selected portion of the HGU-55/P visor with a forehead spacer of variable thickness attached to the upper edge for maintained spacing and accommodating standard aircrew spectacles. It is designed to fit within the existing area defined by the standard helmet and visor.

Head and Shoulder Cowl

The single size head and shoulder cowl is mechanically fastened to the MBU-12/P mask and bonded to the visor. The head cowl extends into a neck dam and shoulder cowl. The shoulder cowl is normally worn between the aircrew member's outer flight suit and CWD inner coverall but could be worn over the flight suit if required. The neck dam is fitted to the individual and trimmed by a life support technician if needed. Hood slack is provided for head movement.

Ventilation and Breathing Manifold

The manifold provides control of the ventilation and breathing air mixtures. One inlet is attached to the outlet side of the C-2 NATO filter with the oxygen hose attached to the in-line outlet. The filter/blower hose is attached to the second outlet. Breathing mixture gas from the C-2 NATO filter passes through one chamber to the oxygen mask hose, and the hood if desired. Ventilation air from the blower passes through the other chamber to the ventilation hose leading to the hood.

Breathing Gas Filter

The C-2 NATO filter is used to filter the breathing mixture. It mounts on the normal oxygen CRU-60/P receiver attached to the parachute harness. The manifold attaches to the oxygen outlet of the unit to provide control of ventilation and breathing mixture for ground and flight operations.

Filter/Blower Unit

The filter/blower unit provides filtered blown air to the hood assembly and mask, when desired. The unit uses a C-2 NATO filter with NATO standard thread. It can be carried by the crew member using a shoulder or hand strap, or hooked to a connector on the PCU-15/P torso harness. For flight, it is stored on board the aircraft in a mounting bracket which has an aircraft power receptacle. When the unit receives aircraft power, its battery is automatically deselected.

Intercommunciation Unit

A conversational unit such as the Gentex unit is required for ground communications. It is powered by rechargeable batteries and connects to the aircrew member's intercom cord. The unit has talk/listen capabilities that permit the user to hear surrounding sounds and speak through an amplified speaker. An accessory cord permits two people to plug into the same unit and communicate privately. The unit can also be used in flight, if required.

Donning and Doffing Procedures

The PIHM can be donned and doffed in a contamination control area or on board an aircraft with an area large enough to stand, using procedures similar to the MBU-13/P. However, the hood and mask are normally donned after the CWD inner coverall followed by the flight suit for wind blast and CWD protection. Assistance with positioning the hood is helpful. Normal doffing requires assistance and procedures to prevent contamination.

In-Aircraft Versus Out-of-Aircraft Configuration

All components, including the blower unit, are used for ground operations. Unassisted transition is possible. The PIHM requires an aircraft mounted bracket and power receptacle for the blower unit.

Integration With Aircraft

A mounting bracket for securing the blower during flight operations will be installed near each crew position. This should require only minor modifications. The proposed battery does not have sufficient capacity for most missions; four hours is the limit. Therefore, electrical power cables which supply aircraft power to each crew position are required.

Fig 1. Aircrew Member in PIHM (front view)

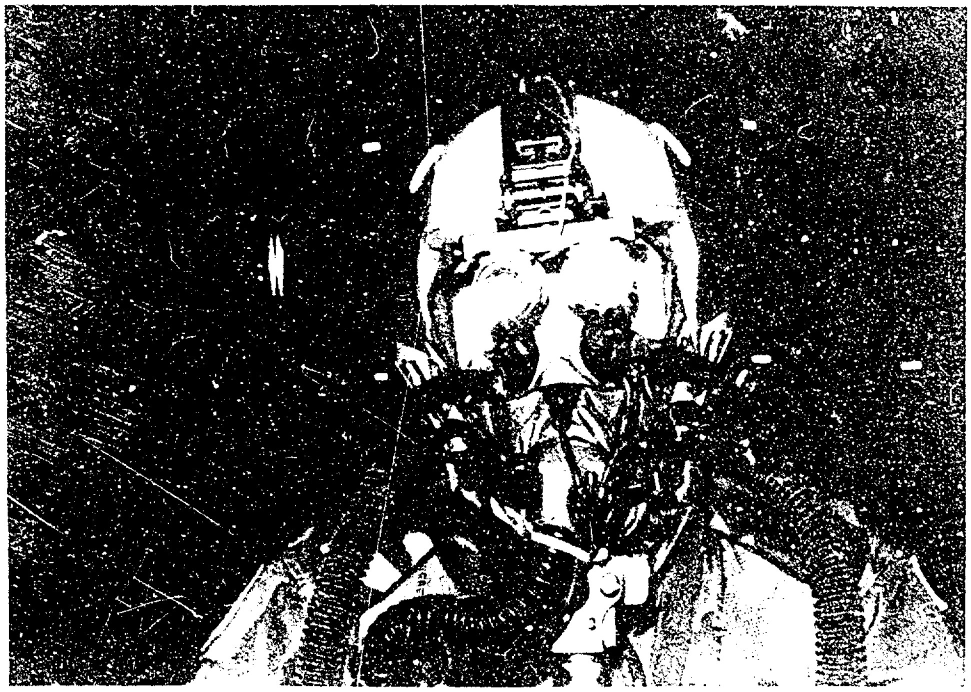


Fig 2. Aircrew Member in PIHM with NVGs (front view)

Fig 3. Aircrew Member in PIHM (side view)

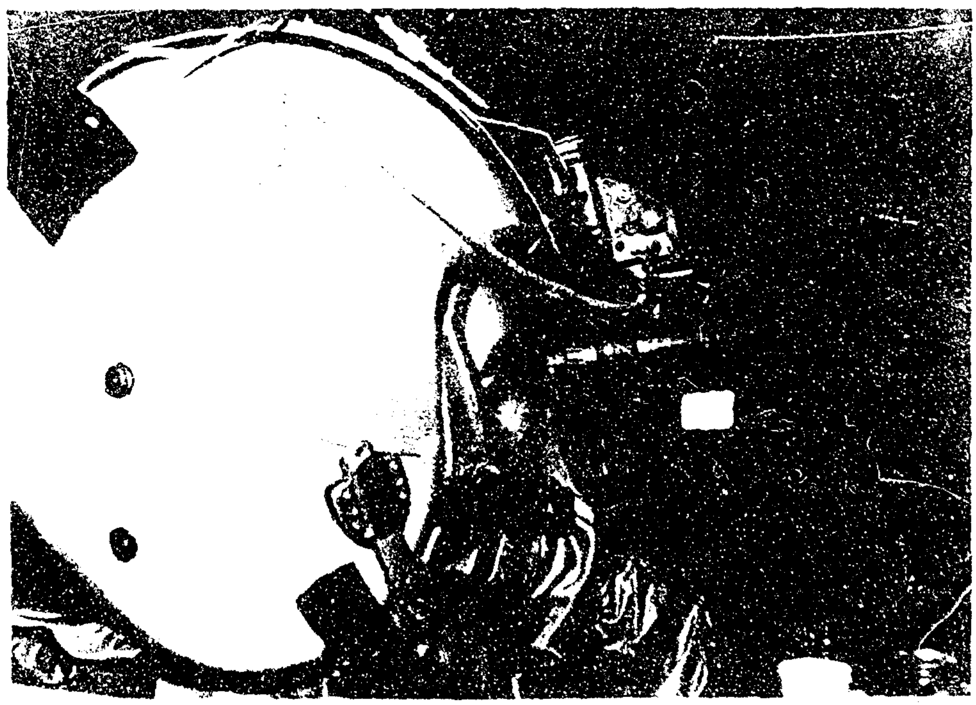
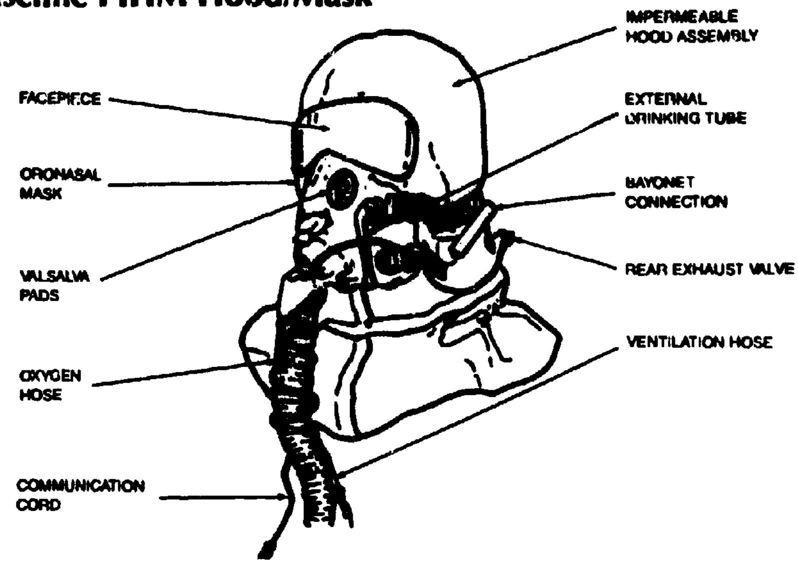
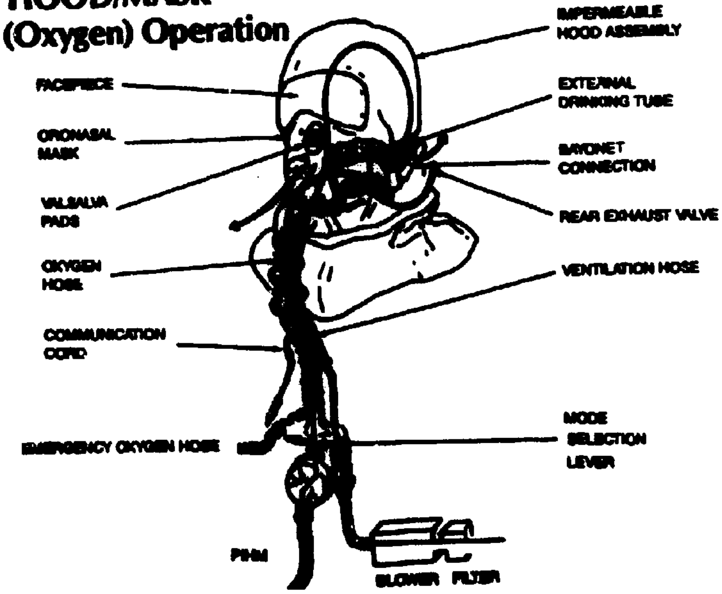


Fig 4. Aircrew Member in PIHM with NVGs (side view)

Baseline PIHM Hood/Mask



PIHM HOOD/MASK Flight (Oxygen) Operation



EVALUATION OF A NEW FUEL WITH HIGHER ENERGY DENSITY

by

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SUMMARY

In order to increase the range and endurance of fighters operating in the far northern regions of Canada, and to extend maritime surveillance capability with existing aircraft assets, the Department of National Defence of Canada has pursued the development of an aviation fuel with a high energy density. The fuel selection criteria included: an energy increase of at least 10% by volume over current NATO F40/JP-4; acceptable performance and durability impact on aircraft systems; and large scale availability at reasonable cost.

This paper provides a description of the analysis which was used to determine the potential benefits to be derived from the use of a high energy density fuel. Mission analyses include discussions which cover fighter - CF-18, maritime surveillance - CP-140 Aurora, and tankers - CC-137, and KC-130, aircraft. The paper then discusses the fuel characteristics which were perceived to have a potential impact on aircraft or engine military performance. The results of engine component rig tests are then briefly discussed to demonstrate how critical fuel blend factors were evaluated to ensure that an optimal energy/performance blend was determined. Finally a description is provided on testing objectives for the subsequent full scale engine performance and durability testing as well as an outline of the final flight certification program for the High Density Fuel (HDF). (25) * Aviation fuels, Refueling in flight.

The test results to date have been most encouraging. There appears to be considerable potential for the introduction of HDF to military service.

NOMENCLATURE

AAR	=	Air-to-Air Refuelling
C	=	Celsius
C/L	=	Centerline station
CF	=	Canadian Forces
CON	=	Configuration
cSt	=	Centistokes
DND	=	Department of National Defence Canada
F	=	Fahrenheit
FUS	=	Fuselage weapon station
HDF	=	High Density Fuel
I/B	=	Wing In-Board pylon station
IFR	=	Instrument Flight Rules
L	=	Litre
MJ	=	Mega-Joules
NM	=	Nautical Miles
O/B	=	Wing Outboard pylon station
TOS	=	Time On Station
W/T	=	Wing Tip station

INTRODUCTION

The Department of National Defence (DND) in Canada was approached by a petroleum firm in 1986 with a proposal for a high energy density fuel which was, for the most part, similar to existing aviation fuels and which could have an operationally significant beneficial impact. The proposal provided that the fuel could be produced in significant quantities, at approximately constant energy costs, and that while some of the fuel characteristics were questionable in light of previous design considerations; further evaluation would be prudent.

It was decided to evaluate the potential for fuel development by:

(1) Determining whether or not a real operational need exists for the extension of the range and/or endurance of any Canadian Forces aircraft fleets. While this may seem a rather obvious point, aircraft mission requirements, as they are currently defined had to be evaluated against existing fleet capabilities to determine if any deficiencies exist and whether those deficiencies could be mitigated through the use of HDF.

(2) The evaluation of the operational benefits of using HDF in aircraft which were identified as potential targets of opportunity for the extension of operational capability would then be carried out. A relative assessment of aircraft range and endurance capabilities on current and the HDF fuel was completed and that assessment is the primary discussion area for this paper.

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(4) Once the operational need had been identified, and the potential for satisfaction of that need through the use of HDF verified, a review would be conducted of the critical fuel factors impacting on energy content, performance, military acceptability, and aircraft and engine durability.

(5) Component rig testing would then be conducted to identify the fuel blend factors which offered potential for energy density improvements and the effects that those blend factors would have on the performance and durability of airborne systems.

(6) The component rig testing would identify the preferable architecture of the fuel, and then full scale engine sea level static, altitude chamber, and flight testing would be used to verify the performance improvements, durability acceptability, and certify the fuel for military use.

OPERATIONAL NEEDS

For any particular mission profile and aircraft configuration, the maximum operating range and time-on-station (TOS) of certain Canadian Forces aircraft are limited by the volume rather than the weight of fuel that the aircraft can carry. This factor is most significant for maritime surveillance operations as current aircraft are heavily tasked to cover the coastlines of Canada. Since the primary combustion process in the gas turbine engine involves burning a given weight of fuel in a given weight of air, it stands to reason that HDF would have a positive operational impact on the ability of maritime surveillance aircraft limited by fuel volume to fulfill more strenuous missions.

Other operational factors need also be considered. The CF 18 aircraft is required to operate extensively in the far northern regions of Canada. Missions are extended by virtue of the territory which must be covered. The consequences of depletion of fuel are catastrophic due to the extreme weather conditions encountered and distance from relief centers. The ability to carry an additional 10% of energy could have significant operational and flight safety benefits for the CF 18 aircraft.

Closely tied to the fighter operations in the previously mentioned, and in many other operational theaters is the conduct of Air-to-Air (AAR) refuelling. Canada has an extensive AAR refuelling mission requirement, and once again, the carriage of fuel having a higher energy content was determined to be beneficial. Tanker range and endurance would assumedly benefit as would the amount of energy which could be transfered to the supported fighter aircraft. Potentially more aircraft could be refuelled with a fixed energy load, or conversely a fixed number of aircraft could be refuelled with a greater amount of energy.

OPERATIONAL IMPACT ASSESSMENT

The operational impact of an aviation turbine fuel with 10% more volumetric energy content relative to NATO F40 was examined for four different Canadian Forces aircraft: the CF-18A, the CP-140 (Aurora), the KC-130 (Hercules) and the CC-137 (Boeing 707). Various mission profiles and weapon/aircraft configurations were simulated for each aircraft in all phases of flight. Expended fuel was accounted for at the end of each phase such that the aircraft would land with its minimum IFR (Instrument Flight Rules) reserves. In this manner, operating range and TOS may be varied independently so as to determine the operational impact due to the increase in energy content realized by a higher density fuel.

For each aircraft, a mission profile is examined which requires it to operate at a certain range from its home base. After a long-range cruise it may either dash to the target and unload its stores (CF-18A), loiter-on-station in an ASW (Anti-Submarine Warfare) role (CP-140), or loiter-on-station and provide air-to-air refueling to fighter aircraft (KC-130 and CC-137).

Regardless of the operational requirements, each simulation determines the fuel expended at the conclusion of each phase of flight. The phases are:

(1) Start/Taxi/Take-Off

(2) Climb to cruising altitude

(3) Cruise to operating area

(4) Fulfill mission requirements

(5) Cruise to home base

(6) Descend to home

(7) Approach and landing

All data such as specific range, fuel flow, TAS(True Airspeed) etc. were modelled as polynomials in the appropriate parameter, i.e., aircraft gross weight or time. By varying the cruise range and loiter time and landing with minimum IFR reserves, each simulation provided a straightforward determination of the operational benefit of HDF on fuel volume limited aircraft.

CF 18A

Three mission profiles were considered for the CF-18A. They are LLLL, LLLH, and HLLH (L=Low, H=High). Figure 1 illustrates the three profiles used in the analysis. For each profile, there were seven combinations of aircraft configurations and weapons (MK-82 SE Bombs, BL755 Bombs, LAU-5003A/A Rocket Launcher with 10 lb RX warhead and nose cones). Tables 1-3 detail the different configurations and store data used in the analysis.

CON	AIRCRAFT STATION								
	LEFT					RIGHT			
	W/T	O/B	I/B	FUS	C/L	FUS	I/B	O/B	W/T
1	AIM-9 (1)	Weapon (2)	Weapons (2)	Clean	330 gal Tank	Clean	Weapons (2)	Weapons (2)	AIM-9 (1)
2	AIM-9 (1)	Weapons (2)	330 gal Tank	Clean	Weapons (2)	Clean	330 gal Tank	Weapons (2)	AIM-9 (1)
3	AIM-9 (1)	Weapons (2)	330 gal Tank	Clean	330 gal Tank	Clean	330 gal Tank	Weapons (2)	AIM-9 (1)

CON = configuration
() = number of stores

TABLE 1. AIRCRAFT CONFIGURATIONS

Store	Weight per Store (lbs)	Drag Index
MK-82 SE	565	6.0
BL 755	610	16.8
LAU-5003	530	8.0
330 gal Tank	230	10.5/14.5
Pylon	130/273	3.0/7.5
VER	175	9.0

N1/N2 = CENTERLINE/WING

TABLE 2. STORES DATA

Number of Tanks	NATO F40 Fuel (lbs) (includes internal)
1	11910
2	13960
3	16010
Total Internal	9860

TABLE 3. USABLE FUEL

The CF-18A Aircraft Operating Instructions (AOI) were used to calculate the range and fuel expended under each profile and configuration. For each dash distance (A or B), a radius of action was determined such that the aircraft landed with 2000+/- 25 lbs of fuel. Each simulation was run with F40 and HDF (1.10x F40). Table 4 shows the percent increase in the radius of action as a result of using a higher density aviation turbine fuel.

The results shown in Table 4 indicate significant operational improvement when using HDF. The percent increase in the radius of action varies from a low of 13% (in itself significant) to a high of 26%. Even though the difference in the radii of action due to the two fuels increases as the configurations change from 1 to 3, the percent difference decreases. After weapons release, the aircraft is much heavier for configuration 3 than for configuration 1. It may cruise further from home but it will also expend fuel at a faster rate.

Under the profile LLLH and configuration 1, Table 4 shows that the operational requirements are not met using either F40 or HDF when armed with BL755 bombs and dashing 100NM. However with LAU-5003 rocket launchers under the same conditions, the requirements are met with HDF but not with F40. This situation also occurs under profile HLLH with BL755's and configuration 1.

CF-18 A RADIUS OF ACTION (NM)

		LLLL						LLLH						HLLH					
		A			B			A			B			A			B		
Weapons	CON	F40	HDF	%	F40	HDF	%	F40	HDF	%	F40	HDF	%	F40	HDF	%	F40	HDF	%
MK-82	1	191	219	15	178	205	16	225	263	17	n/a	239	--	305	359	18	242	304	26
	2	237	269	14	224	257	15	288	332	15	263	310	18	395	454	15	348	416	20
	3	289	326	13	278	316	14	360	410	14	339	394	16	493	558	13	458	536	17
BL 755	1	173	199	15	158	181	17	196	230	17	n/a	n/a	--	255	309	19	n/a	239	--
	3	274	309	13	261	297	14	334	381	14	312	363	16	457	520	14	414	448	18
[illegible]	1	189	216	14	173	202	17	220	258	17	n/a	229	--	295	347	18	231	291	26
	3	285	321	13	273	311	14	349	402	15	331	385	16	485	550	13	447	525	17

% = denotes percentage improvement over F40

CON = Configuration

TABLE 4. CF-18 PERCENT INCREASE IN RADIUS OF ACTION DUE TO HDF USAGE

CP 140 - AURORA

Figure 2 illustrates the two mission profiles considered for the CP-140 aircraft. For each profile, there are two aircraft configurations (labelled A and B). The AOI for the CP-140 was used to determine fuel flow, cruise range and TAS under any gross weight of the aircraft for each profile and configuration. In each simulation, the aircraft cruised to an operating area and, under power of three engines, loitered on station for a definite period before returning home and landing with 5000+/- 25 lbs of fuel. Figures 3 and 4 illustrate the operational advantage when using a higher density aviation turbine fuel in the CP-140 aircraft.

Since the aircraft returns with its minimum IFR reserves, the results in Figures 3 and 4 represent the maximum allowable TOS for any particular cruise range and the maximum cruise range for a particular TOS. Tables 5a and 5b show the percent increase in TOS and cruise range generated by HDF. The percent increase in TOS (Table 5a) varies from a low of 9% for the shorter cruise range (longer TOS) to a high of 48% for the longer cruise range (shorter TOS). The average increase in the TOS, regardless of the cruise range is approximately 1 hour. Table 5b shows that the percent increase in cruise range varies from 11% for a shorter TOS (longer cruise range) to a high of 30% for a longer TOS (shorter cruise range). The average increase in cruise range, regardless of the TOS, is approximately 180 nm.

Cruise Range (nm)	Congig./ Profile	Time-On-Station (hours)		
		F40	HDF	%
500	A/1	9.4	10.2	9
	A/2	8.9	9.9	11
	B/1	8.9	9.7	9
	B/2	8.6	9.6	12
1000	A/1	6.8	7.8	15
	A/2	6.2	7.2	16
	B/1	6.2	7.2	16
	B/2	5.7	6.8	19
1500	A/1	3.8	5.0	32
	A/2	3.0	4.3	43
	B/1	3.1	4.3	39
	B/2	2.5	3.7	48

TABLE 5a.

Time-on Station (hours)	Config./ Profile	Cruise Range (nm)		
		F40	HDF	%
2	A/1	1752	1940	11
	A/2	1646	1832	11
	B/1	1645	1821	11
	B/2	1564	1739	11
4	A/1	1464	1655	13
	A/2	1351	1540	14
	B/1	1362	1540	13
	B/2	1274	1452	14
6	A/1	1139	1328	17
	A/2	1026	1217	19
	B/1	1038	1214	17
	B/2	955	1137	19
8	A/1	775	960	24
	A/2	673	863	28
	B/1	673	845	26
	B/2	609	793	30

(% denotes percent improvement)

TABLE 5b.

TABLE 5. CP 140 PERCENT INCREASE IN CRUISE RANGE AND TIME-ON-STATION

KC-130 - HERCULES

Figure 5 illustrates the mission profile for the typical KC-130 mission. All calculations on the KC-130 tanker were based on the variant configuration consisting of external fuel tanks and refuelling pods installed. This configuration resulted in a drag index of +18. The AOI for the CC-130 was used to determine distance, fuel flow, TAS etc. at all points in the profile.

In terms of fuel capacity, there are stress factors to be considered when distributing fuel in the KC/CC-130. For instance the wing tanks are weight (not volume) limited and structural damage may occur if their capacity to hold 62920 pounds is exceeded. However the KC-130 tanker configuration has an additional 3600 gallon tank (23400 pounds of F40) in the cargo compartment which is volume (not weight limited) and could be used to carry HDF.

In its role as a tanker, the KC-130 would cruise to a rendezvous point, loiter for a period of time, meet the CF-18's and refuel each fighter before returning home to land with 6500 +/- 25lbs of fuel. Figures 6a-6f show the results of refueling up to 6 CF-18A's with 10,000 lbs of fuel each. Figures 7a and 7b show the results of refueling 1 and 3 CF-18A's with 15,000 lbs each. Plots for 2 or 4 aircraft (refueled with 15,000 lbs each) are not included since they are approximately equivalent to refueling 3 and 6 aircraft respectively with 10,000 lbs each.

In aerial refueling, the KC-130 has the advantage of providing tanker support to CF-18 aircraft on northern patrol. With this capability, the fighters could extend their time on partrol and, thus, provide 24 hours coverage with fewer missions and fewer aircraft. Clearly, the economic implications are substantial.

Figures 6 and 7 show the operational impact of utilizing HDF in a typical KC 130 tanker mission. Use of the fuel increases KC 130 cruise range by 50-80 nm or loiter time by 30-40 minutes. Although these benefits are marginal, a substantial operational improvement can be achieved in the energy off-loaded to the CF-18 aircraft as shown in Table 4.

CC-137 (BOEING 707)

Figure 5 also illustrates the mission profile for the CC-137 tanker. The AOI for the CF-137 was used to determine distance, fuel flow, TAS etc. at all points in the profile. The tanker configuration also accounted for an additional 5% in fuel expenditures in each phase.

As for the KC-130, the CC-137 would cruise to a rendezvous point, loiter for a period of time, meet the CF-18's and refuel each aircraft before returning home to land with 16000+/- 25 lbs of fuel. Figures 8a-8f show the results of refueling up to 6 CF-18A with 10,000 lbs of fuel each. Figures 9a and 9b show the results of refueling 3 CF-18A with 15,000 lbs each.

Similar to the KC-130, the CC-137 has the capability of providing tanker support to fighter aircraft. Figures 8 and 9 show the justification for using HDF instead of F40 in aerial refueling. As an example, Figure 8d shows the results of refueling 4 CF-18A with 10,000 lbs of fuel each. If F40 was used, with a cruise range of 1000nm, the CC-137 could loiter for 5.2 hours, refuel all aircraft and return home with 16,000 lbs of fuel. If HDF was used, the time to loiter could be extended to 8.9 hours (+71%). On the other hand, if the loiter time was fixed at 2 hours, the tanker could cruise for an additional 200nm with HDF and still refuel all 4 CF-18A's.

The results of the operational impact assessment show substantial gains in operational performance using HDF instead of F40.

For the CF-18A, a higher density fuel not only extends the operating range but in certain cases fulfils mission requirements which would only be marginally, if at all possible if F40 had been used. In the case of the CP-140, the results also indicate significant operational improvement. The CP-140 can add 1 hour to fulfilling its maritime surveillance role or extend its operating range 200 NM beyond its normal limits. For the KC-130 and CC-137, each tanker could refuel more aircraft, cruise for longer distances and/or loiter on station for a longer period of time. Furthermore, the refueled fighters are able to patrol over longer distances and for longer times using HDF, thereby decreasing the number of missions and aircraft needed to patrol, and increasing the patrol area.

FUEL PERFORMANCE CRITERIA

It is now viable to develop a high energy density fuel while retaining acceptable performance characteristics, and minimal negative operational and durability effects. F40 is termed a wide cut fuel as it is distilled over a wide boiling range. Its' properties approach the ideal from the operational perspective. F40 has a low freeze point, low viscosity, low flash point, high volatility, and burns efficiently and cleanly. Typically F40 performs well throughout all flight regimes, and due to its' relatively low viscosity and high volatility, demonstrates good low temperature startability. By way of comparison F45 (JP5), is distilled over a very narrow boiling range and is blended to be a fuel which can be safely stored. Unfortunately, the very properties which make it a safe fuel, result in its performance being poorer than F40 in terms of both startability and efficiency. These two fuel provide what can be considered the bounds used to determine the acceptability limits and operational goals for HDF. HDF performance should ideally approach that of F40, but will not have characteristics which are less acceptable than those of F45. A brief discussion on fuel characteristics is provided in order to provide a fundamental understanding of the considerations which identified the testing required to determine the HDF specification, and verify its operational acceptability.

The first and foremost quality to be discussed is that of heat of combustion. Within very narrow bounds, the heat of combustion, which is a direct expression of energy content, is constant for hydrocarbon fuels on a mass basis at approximately 43.5 MJ/KG (18500 BTU/LBM). Thus to achieve a higher energy density on a volumetric basis, the specific gravity of the fuel must be increased. The means of increasing the specific gravity of a hydrocarbon fuel is to increase the aromatic content of the fuel. The inclusion of a high percentage of aromatics requires access to the appropriate crude stocks and unfortunately also carries some performance penalties. Increasing the volumetric energy content can potentially cause a number of engine operational problems. Control systems which do not provide for mass flow metering of the fuel can produce excessive acceleration rates, overtemperature conditions, or overspeeding, which can in turn, cause durability or internal aerodynamics problems.

Aromatics are the heavy hydrocarbons in a fuel blend and therefore are required to increase to produce a more dense fuel with increased energy. Aromatics when burning, produce a more luminous flame which enhances heat transfer to the combustor walls. This increased heat transfer results in higher skin temperatures and hence shortened component lives. Increased aromatics also results in a somewhat decreased combustion efficiency which manifests itself most significantly in the production of undesireable emissions, most notably smoke. Thus in achieving a higher energy density fuel, hot section durability can be lessened, and increased smoke can be expected. The increased smoke emissions are operationally significant for the fighter missions, and will have increasing importance in maritime surveillance as subsurface-to-air weapons become more heavily utilized.

The vapour pressure which a fuel blend exhibits will be high if there is a large percentage of volatile components. High volatility is desirable for good low temperature start capabilities; however that same characteristic can give rise to safety problems and other problems such as fuel delivery pump vapour lock. The HDF goals were aimed primarily at performance as the safety issues associated with shipboard fuel storage are of minor concern to the CF. As such, the HDF vapour pressure was targeted at the F40 level.

The flash point concerns mirror those of vapour pressure, and once again it was determined to attempt to obtain good low temperature start characteristics by maintaining a relatively low flash point.

Freeze point, cloud point, and viscosity are characteristics which are interrelated and can be discussed together. The freeze point and cloud point are essentially the same and describe when wax begins to crystallize in the fuel. The formation of wax is significant in that the wax can clog filters or fine orifices causing fuel metering problems. Typically freeze point and viscosity vary proportionally, a high freeze point indicating a high viscosity at low temperatures. Viscosity is recognized as a critical parameter in terms of fuel nozzle spray patterns and atomization which in turn affect cold startability and flame stability. As stated previously, the HDF cold start characteristics were considered to be . ..portance in assessing that fuels acceptability due to both cold weather operational and altitude relight considerations.

The final fuel characteristics to be discussed are the chemical contaminants. Tar sands derivatives contain higher levels of such contaminants as mercapton sulfur which attacks elastomers in fuel system and engine control components. The goals of the HDF blend would have to be to minimize the trace element contaminants and also to assess the effects of the actual contaminant levels during component testing.

TEST PROGRAM

The specification of HDF characteristics, and verification of the fuels operational acceptance was to be carried out in five phases as described below.

An initial test program was used to identify the critical blend factors for HDF to assess whether the operational goals were possible at the increased density level. This testing was conducted at Universite Laval (Ref 5.) and utilized a scaled research combustor at two constant temperature, constant pressure conditions. The combustor employed a pressure jet atomizer and had twelve thermocouples installed at four planar locations on the combustor wall. Table 6 provides a comparison of the critical characteristics of the five sample HDF blends, as well as for the as-tested F40.

Property	HDF A	HDF B	HDF C	HDF D	HDF E	F40
Specific Gravity	.846	.863	.841	.849	.851	.754
Hydrogen Content (mass)	.133	.129	.136	.133	.132	.145
Viscosity @ 293K (cSt)	2.88	3.13	2.78	3.16	2.96	.756
Net Calorific Value (MJ/L)	36.9	37.3	36.9	36.9	37.1	32.8

TABLE 6. - PROPERTIES OF TEST FUELS

This test program confirmed the expected fuel performance characteristics. All HDF blends burned slightly less efficiently, and produced more pollutants and visible emissions than the F40. Some increase in wall temperatures in the primary combustion zone of the combustor was observed for all HDF blends; however, in general the effects were not considered significant. Once past the primary zone, there were only negligible wall temperature differences. In fact, this initial test phase indicated that although further testing would be necessary to quantitatively assess visible emissions; there was no obvious impediment to the further testing of the HDF. For the most part all HDF blends performed equally well.

The second phase of testing was conducted in a combustor rig at the Gas Dynamics Lab of the National Research Council of Canada (Ref 6.). As opposed to the phase 1 atmospheric pressure testing, the combustion conditions in phase 2, approached the normal operating temperatures and pressures of the T56 series of engines used in the CP140 (P-3), and CC130 aircraft. For this test program F40 and Jet A-1 (NATO F35 and similar to F34) were used for comparative purposes. The HDF blends tested were the same as in the Laval tests. The significant conclusions for this test program were that:

a. Emission species for all test and reference fuels were similar in nature and concentration levels;

b. No significant increases in wall temperatures were noted for any of the test or reference fuels;

c. The smoke levels for the all HDF blends showed little variance, and were slightly greater than for F35 and F40, but not unacceptably high; and

d. Exhaust gas temperatures were higher for the HDF fuel blends than for F40, which may be significant in terms of IR signature.

The final conclusion of the Ref 6. report was that the HDF fuel performed similarily to the reference fuels, and that there appeared to be no reason for concern about conducting full scale engine testing.

The third phase of testing was conducted at Pratt and Whitney Canada in conjunction with advance igniter testing (Ref 8.). This phase of testing was intended primarily to verify the cold start characteristics of the HDF type blend. The same five HDF blends were tested along with F40 and F35 reference fuels in a PW300 full annulus test rig. The test rig employs 22 air blast nozzles and two hybrid pressure atomizing/airblast nozzles. Combustor pressure drop was varied from two to five inches of water, and the inlet temperatures varied down to -29C (-20F). The low pressure drops and temperature represent a severe test condition, particularly for air blast nozzles which depend on relatively high velocities to assure adequate atomization.

Once again the test results were most favourable for the HDF blends. The HDF blends started down to the lowest temperatures at the minimal pressure drops which represent the most severe relight conditions. The HDF blends performed as well as the F40 reference fuel and exceeded the F35 start characteristics. The high viscosities of the HDF blends were anticipated to cause a worsening of the fuels cold start capabilities but that was not borne out in the test observations. These test results challenge some previous concepts of fuel performance.

At the time of writing, the previous three test phases had been completed. The remaining two test sequences are intended to identify fuel acceptability using full scale engine tests, and finally, flight test. Full scale engine testing will be conducted on the T56 engine and the F404 engine used in the CF 18. The flight testing will most likely be carried out using a CF 18 aircraft. Engine full scale testing will have the following objectives:

a. To verify acceptable engine performance using HDF fuels, this will be achieved by conducting back-to-back power hooks on certified laboratory quality test stands, using F40 and HDF;

b. To verify that no accelerated hot section duress occurs by the conduct of limited scope Accelerated Mission Testing (AMT) (150 hours for the T56, 50 hours for the F404);

c. To quantify both visible emissions and pollutants produced by the use of HDF; and

d. To conduct cold soak atmospheric starts.

REFERENCES

1. Aircraft Operating Instructions CF18A/CF 18B HORNET (U), C-12-188-NFM/MB-001, 31 December, 1987 (U).

2. Aircraft Operating Instructions CF 140 AURORA (U), C-12-140-000/MB-001, 27 June, 1986 (U).

3. Performance Data for Lockheed Hercules (U), C-12-130-J00/MB-002, 20 June 1985 (U).

4. Aircraft Operating Instructions CC 137 Flight Test Procedures (U), C-12-137-000/MB-204, 19 December, 1986 (U).

5. Kretschmer D., LaViolette M., " Comparison of Five High Density Fuels", Universite Laval Report No. 183, January 1989

6. Campbell I., Test Report of Department of National Defence Strategic Military Fuels, National Research Council Report CTR-GD-017, February 1990

7. McCaldon K., Critchley I., Sampath P., "Plasma Jet Ignition Research Final Report", September 1989, Pratt and Whitney Canada Proprietary.

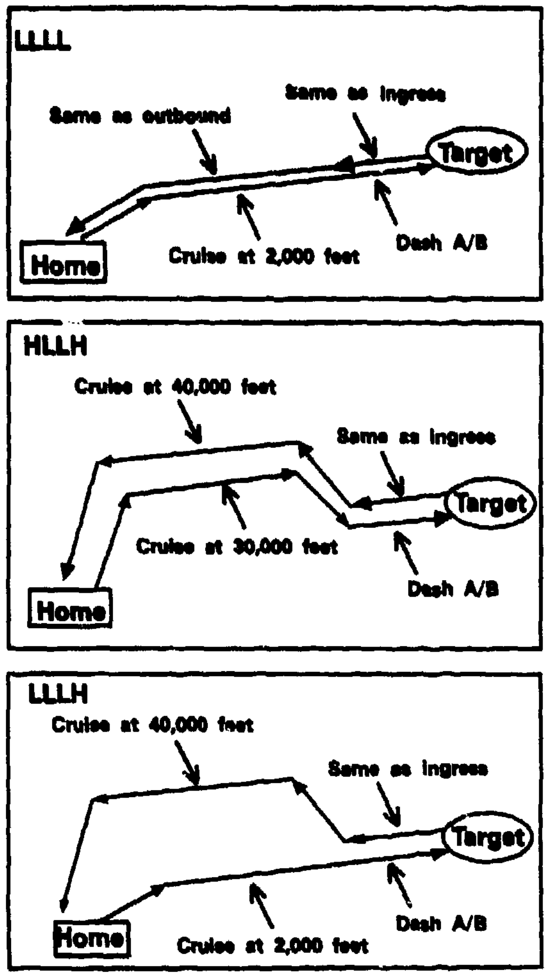

Fig.1 CF-18A Mission Profiles

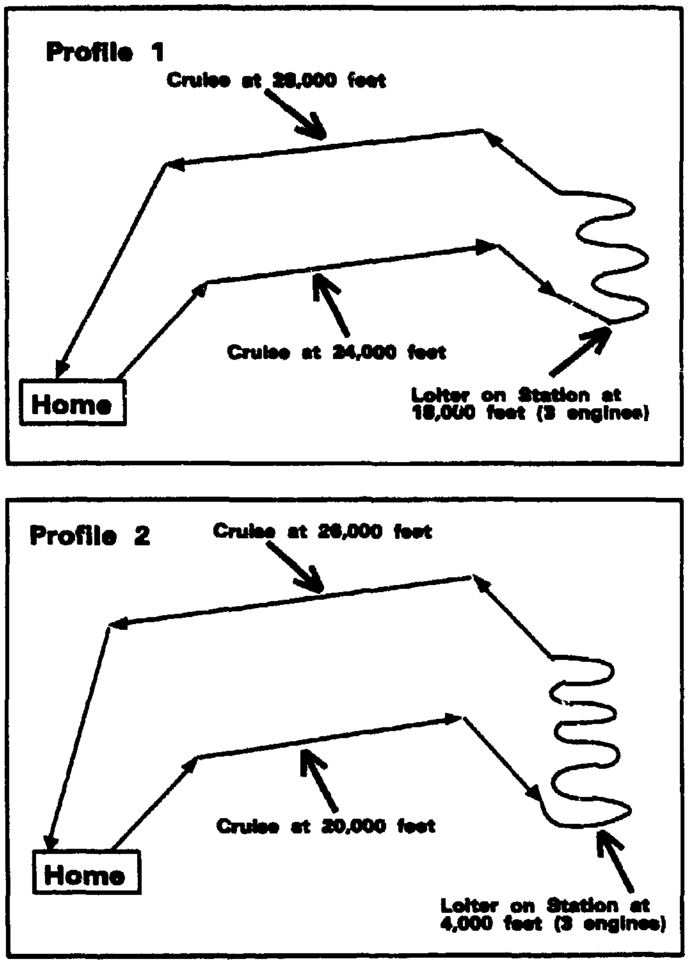

Fig.2 CP-140 Mission Profiles

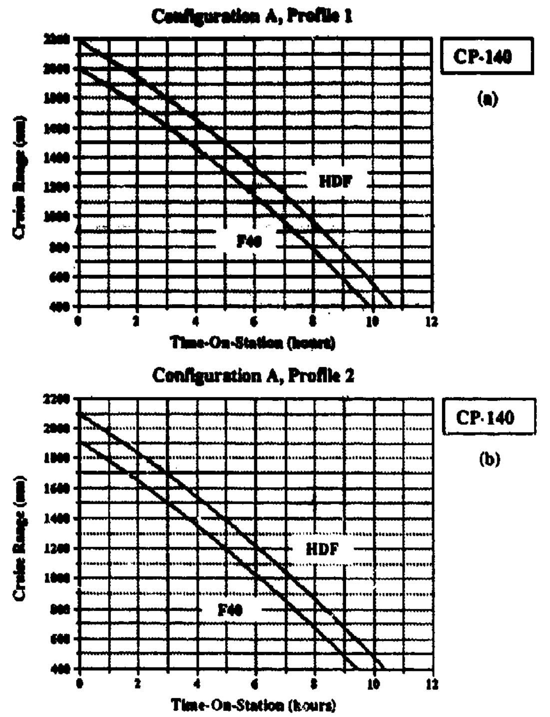

Fig. 3(a,b) Improvements in Cruise Range and Time-On-Station by using a High Density Fuel (Configuration A)

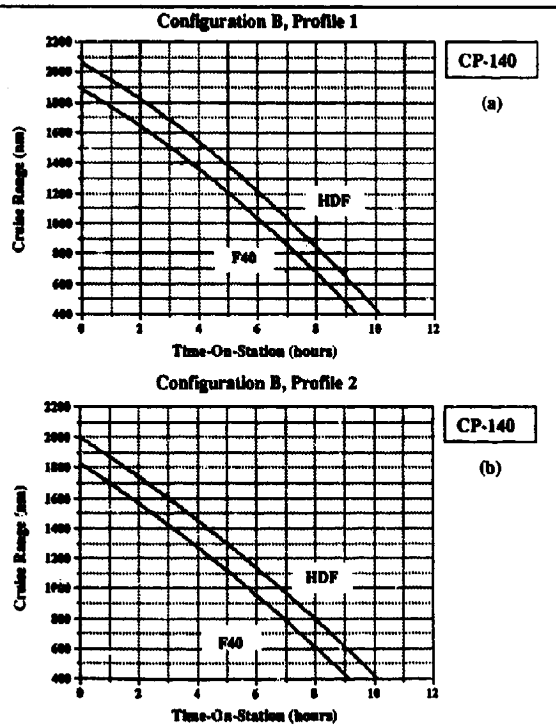

Fig. 4(a,b) Improvements in Cruise Range and Time-On-Station by using a High Density Fuel (Configuration B)

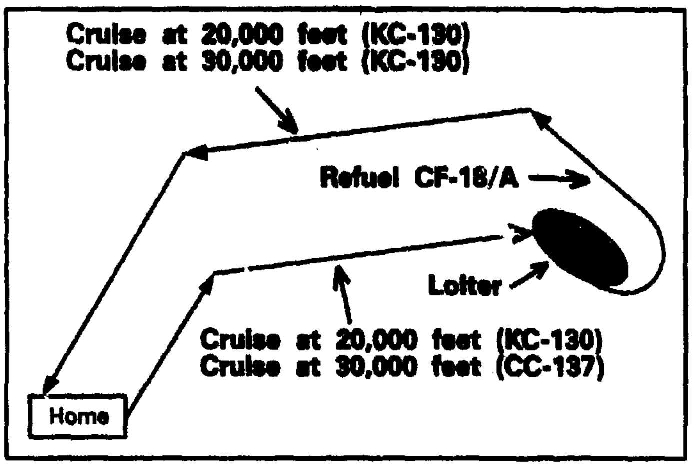

Fig.5 KC-130 and CC-137 Tanker Mission Profile

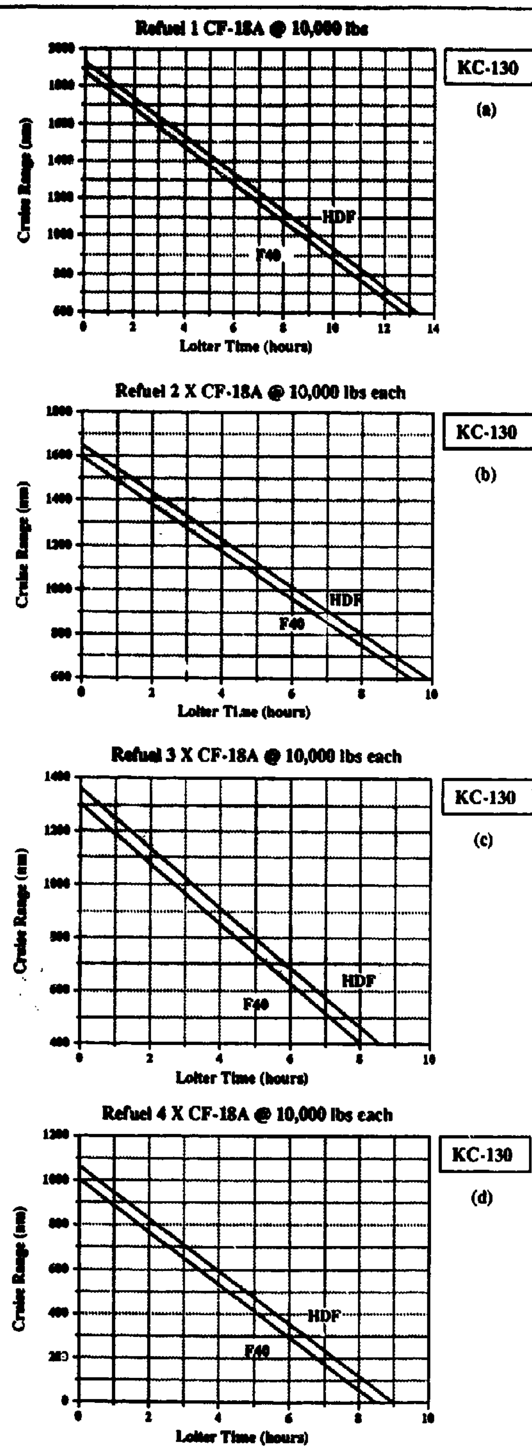

Fig. 6(a-d) Improvements in Cruise Range and Loiter Time in aerial refueling by KC-130 aircraft

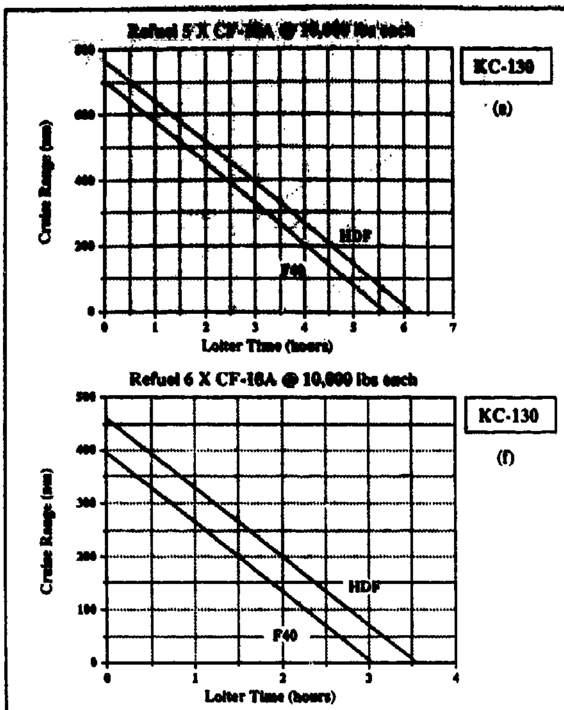

Fig. 6(e,f) Improvements in Cruise Range and Loiter Time in aerial refueling by KC-130 aircraft

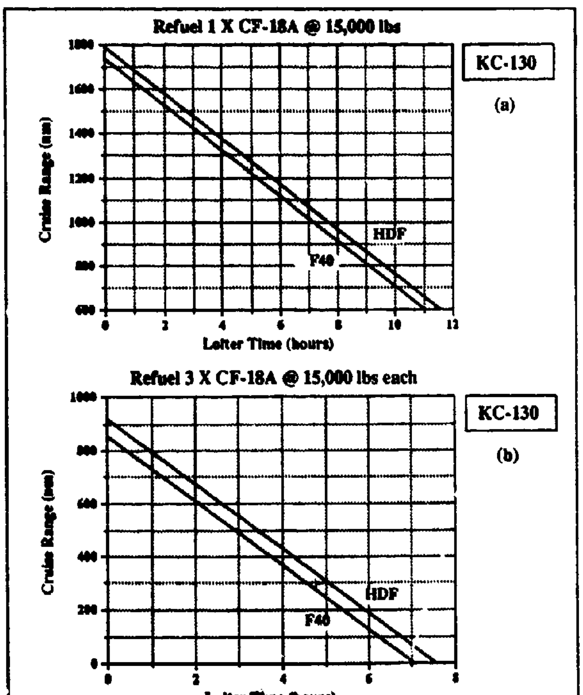

Fig. 7(a,b) Improvements in Cruise Range and Loiter Time in aerial refueling by KC-130 aircraft

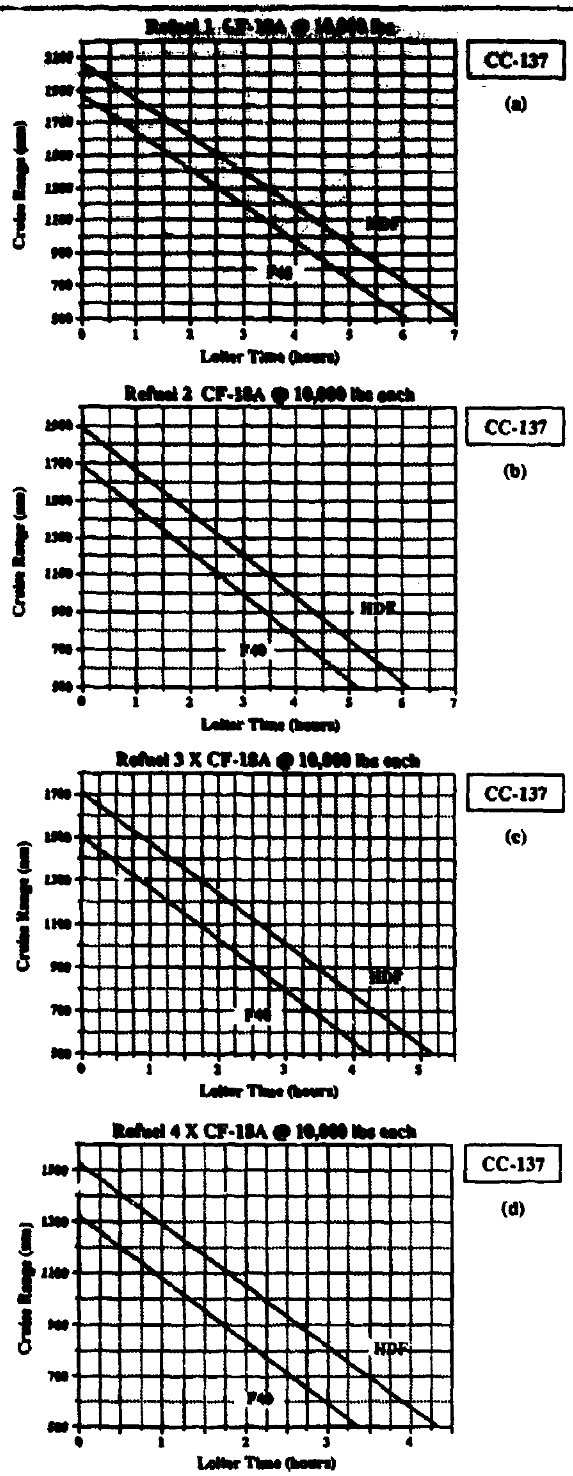

Fig. 8(a-d) Improvements in Cruise Range and Loiter Time in aerial refueling by CC-137 aircraft

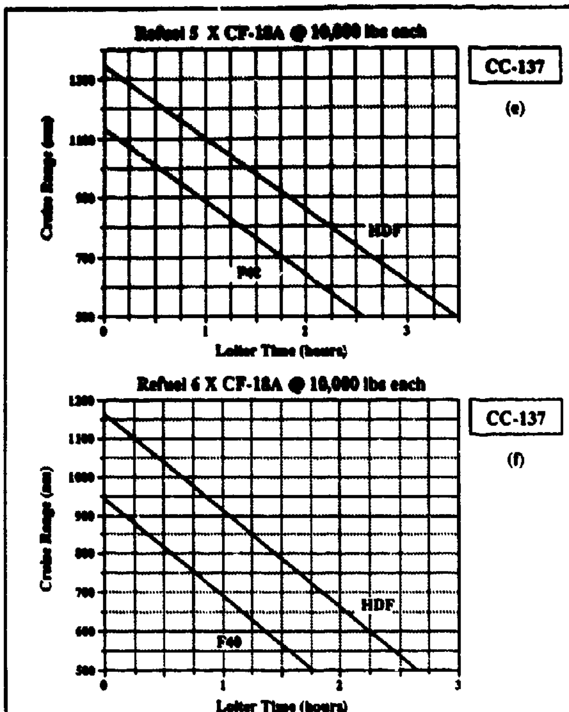

Fig. 8(e,f) Improvements in Cruise Range and Loiter Time in aerial refueling by CC-137 aircraft

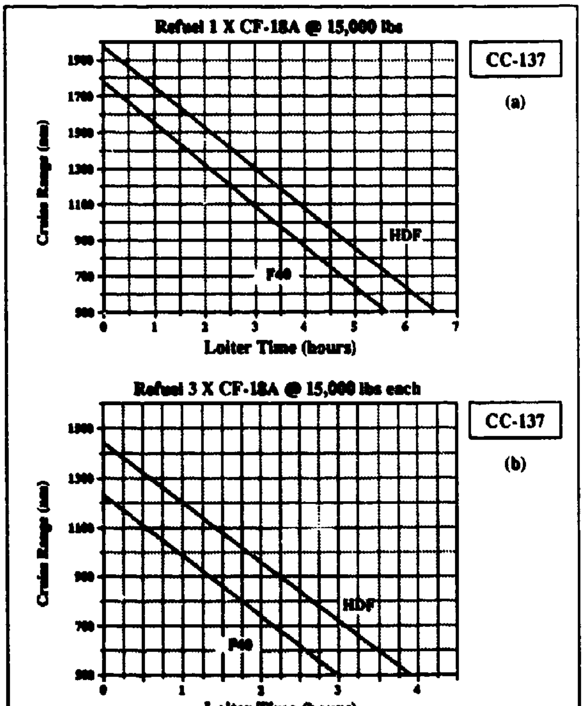

Fig. 9(a,b) Improvements in Cruise Range and Loiter Time in aerial refueling by CC-137 aircraft

THE POWERPLANT OPTIONS FOR A FUTURE LARGE AIRCRAFT

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SUMMARY

"Future Large Aircraft" is a generic term used to describe a future medium sized tactical transport aircraft and derivatives for other roles. Its design will utilise modern technology to provide a replacement for airforces' mixed fleets of Hercules, Transall and a multitude of other aircraft used in tanking, maritime patrol, and other such roles.

Studies conducted so far have shown the powerplant to be the key technology for a new military transport aircraft. Relative to the Hercules and Transall, large gains in capability, and savings in cost, are available with modern powerplants. The influence of powerplant selection is so critical that it is likely to drive the mission capability that can be economically provided.

This paper identifies the main design requirements for this type of aircraft. The benefits of modern technology when applied to both airframe and engine in a military transport are discussed. Turboprop, turbofan, and propfan engines are compared, and the benefits and availability of civil engines reviewed.

Finally, several different aircraft solutions are presented, covering the range of possible powerplants, and their characteristics compared.

25 * Military air...
* Jet transport aircraft

List of Abbreviations

BURR	-	Basic Unscheduled Removal Rate
C/USG	-	Cents per US Gallon
EROPS	-	Extended Range Operations
IFSD	-	In Flight Shutdown
MMH/FH	-	Maintenance Manhours per Flying Hour
MTBM	-	Mean Time Between Maintenance
MTOW	-	Maximum Take Off Weight
OPR	-	Overall Pressure Ratio
SFC	-	Specific Fuel Consumption
TET	-	Turbine Entry Temperature

N.B: Abbreviations explained in the text are omitted.

INTRODUCTION

"Future Large Aircraft" (FLA) is a generic term used by the FLA Exploratory Group (FLAEG) of the Independent European Programme Group (IEPG) to describe future, medium-size (approx 75-125 tonnes AUW [All Up Weight]) transport aircraft, and derivatives intended for tanking, maritime patrol, airborne early warning, electronic reconnaissance or other large aircraft roles.

BAe have been working formally with other companies since December 1982 on a transport aircraft to replace the C-130 Hercules and C-160 Transall. Rolls-Royce and other major engine manufacturers have supported this work by providing comprehensive powerplant data. It should be understood that although this paper is presented under a joint British Aerospace/Rolls-Royce banner there is no agreement or arrangement between British Aerospace and Rolls-Royce on this type of aircraft. The co-operation between the two companies on this paper was arranged purely to give a balanced view on the topic presented, representing the airframe and engine manufacturer's viewpoint. The content of this paper expresses the opinions of the authors and does not represent official policy of British Aerospace, or Rolls-Royce.

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TECHNOLOGY AVAILABLE FOR FLA

Figure 1 shows the large gap in technology available for a Hercules/Transall replacement. In the civil transport field there have been several generations of aircraft developed since the 1950's, progressing from the Boeing 707, to the current state of the art, the Airbus A320. Big improvements have been made in operating economics, reliability, maintainability, safety, comfort and noise. For the military, in several countries, fighter aircraft have continued to push back the frontiers of technology, eg: the defence of the UK now depends on the Tornado whereas the Hawker Hunter was the mainstay in the 1950s. USAF Military Airlift Command have taken advantage of technologies available with the C141, C5 and the current programme, the C17. During this time there has not been a complete vacuum for the Tactical Transport. In the 1960's in the UK, the Armstrong Whitworth AW681 was under development, then cancelled. In the 1970s in the USA, YC14 and YC15 prototypes were flown, then axed. All these programmes placed a big emphasis on short field capability which drove the complexity, weight and cost up and hence led to their downfall. In the meantime the majority of the world's air forces have made do with Hercules levels of performance and sales have reached 1900.

The current emphasis is to utilise established technologies available from civil transports in a new design to replace the Hercules and Transall. Where readily available, capability gains will be made. This is not the type of aircraft where the customer needs are pushing back the frontiers of technology. Modern technology will be used to offer a cheaper and a more capable answer.

The technology which has had the most impact and in the main driven aircraft design throughout aviation history has been the powerplant. In the last thirty five years the turbofan type of powerplant has dominated the thinking of designers of civil transports. Immense improvements have been made in performance, weight and reliability, all of which have led to the huge growth of civil air transport. Recently reliability improvements have allowed designers to develop long range twins. The improvements offered by powerplants are described later in this paper.

During the 1980s high speed propellers were given significant attention, driven by a four-fold increase in fuel price and forecasts for still further increases. For all but commuter aircraft, propeller development had practically stopped in the 1950s. Aircraft projects by several major manufacturers, for new and developed aircraft, were dominated by advanced open rotor powerplants, particularly for capacities around 100 to 150 seats. Proof of concept research was led by three major flight test programmes. The fuel saving potential of this type of powerplant led to its selection as the baseline for FIMA (Future International Military Airlifter) studies in the late 1980s. Hence published data on FIMA aircraft featured mainly a four contra-rotating propeller solution as shown on Figure 2. Recently, civil studies have concentrated mainly on turbofans. The situation has been influenced mainly by the fall in relative fuel price over the last few years. Also, although the technology has been demonstrated, the airlines have shown reluctance to take what they consider to be the risk of an immature product.

DRIVING INFLUENCES ON DESIGN

The design process for an aircraft of this type is shown on Figure 3. The design must achieve a required wartime capability which is significantly different to its peacetime usage. Peacetime operation is however a major consideration as it drives Life Cycle Costs. Powerplant selection has a very strong influence on this process. Powerplant selection will drive the aircraft configuration and its geometry to achieve the requirements stipulated. To achieve a given level of field performance with alternative types of powerplants will require different compromises in high lift systems and wing geometry. Fuel volume may or may not be a driver on wing size, being dependent on the fuel consumption of the powerplant.

Requirements usually get somewhat compromised by cost; therefore powerplant selection will have a major influence on the level of capability that is affordable.

FLA CONSIDERATIONS

The Payload-Range capability of an FLA is shown in comparison with the C-130 and C-160 on Figure 4. FLA requirements are not yet fixed, but for all nations the capability desired is far greater than that of the aircraft to be replaced.

Current FLA concepts envisage a 100Kt speed advantage and a much larger fuselage than the C-130. This is in order to allow side by side loading of wheeled vehicles and avoids the bulking out problems of the existing aircraft. Field capability is also better than that of the Hercules. The gross weight of an FLA is likely to be 80-115 tonnes compared with 70.3 tonnes for the C-130H. Modern technology will enable major gains in capability to be achieved with only a modest increase in weight.

A weight breakdown comparison of the C-130 and an example FLA are depicted on Figure 5. The FLA illustrated is powered by four turbofans and has a maximum payload of 25 tonnes. A design range with maximum payload of 2350nm has been assumed. This shows that even with greater payload and range capability, FLA retains a similar breakdown. The payload of the Hercules is shown at its design case of 2.5g whereas the FLA payload is illustrated at 3.0g. The powerplant plus fuel weight is shown to account for a major fraction on both aircraft.

One of the major benefits of modern technology is illustrated by Figure 6 which compares reliability breakdowns of the C-130H and FLA. The FLA, despite being a larger more capable aircraft, is shown to suffer far fewer failures than the current aircraft. This will have a strong influence on availability which in current C-130 fleets is poor by modern standards. Reliability and availability have an impact on fleet size required, which of course is directly linked to fleet cost and life cycle cost. Powerplant problems are shown to account for a significant proportion of the failures on the current aircraft. On FLA the fraction of failures which is powerplant driven is shown to be lower. The gain in reliability of powerplants in the last thirty-five years, which is very well established, is dealt with later in this paper.

A further illustration of the benefits of modern technology is shown in Figure 7. The maintenance manhours per flying hour are shown to be dramatically lower for the FLA than for the C-130H. In addition to the strong influence on life cycle costs this also directly relates to the manpower required. Manpower shortages are expected to be an even bigger problem in the future than today. Civil contracting of military aircraft maintenance is already established and is likely to become even more necessary in the future, due to increased pressure for reduction of defence spending. For greater flexibility in the places where maintenance is conducted, it is important that the military aircraft are kept abreast of modern systems and maintenance procedures. Otherwise civil maintenance concerns will either charge far more or reject the work as their staff will not be suitably trained. This is particularly relevant to the engine maintenance, which although making a major contribution to the overall reduction in maintenance manhours required, remains a major contributor to FLA maintenance requirements, amounting to about one third of the total maintenance manhours.

The impact of the maintenance cost reductions on Life Cycle Costs is illustrated on Figure 8. The acquisition cost per aircraft for an FLA, to meet the requirements being asked for by European Air forces is likely to be significantly greater than the C-130H. This is counter-balanced by major reductions in both airframe and engine maintenance costs to enable comparable life cycle costs per aircraft to be achieved. To achieve a given airlift capability the fleet size of a Hercules fleet would have to be 50% to 100% greater than a fleet of FLA. Hence the C-130 fleet would have considerably greater Life Cycle Cost for a given airlift capability. The figure also illustrates the major reduction in personnel required for an FLA.

ADVANCES IN ENGINE TECHNOLOGY

The benefits of modern military transport aircraft over their turboprop powered predecessors have just been demonstrated. The contribution of the powerplant to these benefits will now be considered in more detail.

Military aircraft which are primarily intended for active warfare, such as fighters, impose different constraints on engine design from those which are intended for support duties. FLA is primarily intended as a transport aircraft, and although it may see active service, the engine design considerations are closer to civil transports than to military fighters. In design terms this means an engine optimised for low fuel burn and high reliability rather than high thrust to weight ratio.

Trends in overall efficiency of civil transport engines are illustrated in Figure 9, and described in Reference 1. The change from propeller engines to turbojets was motivated by the high speed capability offered by the latter, and it was not until the introduction of the high-bypass turbofan that the overall efficiency offered by the piston engine was equalled.

Turboprops offered considerably better efficiency than early turbojets, but cheap fuel allowed the speed advantage of the jet to predominate on all but short range applications. However, the large rise in fuel price in the early 1980's prompted a propeller renaissance in the form of advanced turboprops and contraprops. These new derivatives offer much higher speed capability, combined with higher efficiencies.

Between the turbofan and the propfan lie advanced ducted engines. They combine some of the propulsive efficiency gain of the advanced propeller with the speed capability of the turbofan.

The aero-powerplant story could turn full circle, with a return to piston engine powered propellers, if speculative proposals such as the adiabatic diesel become practical propositions. However, such proposals are unlikely in today's market conditions, given their weight, cost, and risk penalties.

Of the powerplant options shown, turboprop, turbofan and propfan were considered the most suitable for FLA. Advanced ducted propellers do not yet offer sufficient economic incentive to warrant their introduction into airline service, although much research work is being carried out in readiness for more favourable market conditions.

Turboprop development slowed through the 1970's, until the introduction of propfan studies in the 1980's. However, the component and cycle advances achieved in turbofan development can easily be incorporated into turboprops. Figure 10 demonstrates how the steady improvements in turbofan component and cycle efficiencies were achieved. The introduction of the high bypass single stage fan in engines like the Rolls-Royce RB211 gave the large step increase in propulsive efficiency.

If Figure 10 were drawn for gas turbine propeller engines, a similar story would unfold. Cycle and component efficiencies would gradually increase, and contra-rotating propellers have brought a significant propulsive efficiency gain.

Rising cycle efficiencies result from increasing combustion temperature levels and increasing overall pressure ratios; this is demonstrated in Figure 11 and discussed in Reference 2. It is important to note that the trend for increasing cycle pressures and temperatures is flattening off. High cycle temperatures and pressures, near to the technology limit, result in a sharp fall-off in component life and increased maintenance cost. In recent years engine design has moved away from the absolute technology limit to the benefit of maintenance cost so as to achieve the lowest cost of ownership. The law of diminishing returns ensures that a large increase in cycle temperature or pressure is necessary for a relatively small performance gain, but with a disproportionately large increase in maintenance costs.

Mature reliability trends for two Rolls-Royce engines are shown in Figure 12. Generally speaking, each new generation of engine has twice the mature reliability of its predecessor. This improvement is achieved by designing in reliability from the outset, in both the mechanical and cycle design. The reliability advantages of a derivative rather than a new design are, therefore, obvious.

The importance of reliability in an aeroplane should not be underestimated. Apart from obvious safety benefits, the economic and operational advantages are considerable. A delayed takeoff or aborted flight can involve expensive rescheduling and passenger hospitality, apart from the cost of engine repair. More insidious aspects of unreliability are the effect on operator image, and the increase in fleet size necessary when some aircraft are unserviceable.

In military terms, in addition to the economics of reliability, there are the crucial effects on operational capability of unserviceable aircraft, or the possible political embarrassment of an aborted flight.

POWERPLANT CHOICE

Having looked at the advances in efficiency and reliability of civil aero engines over recent years, the choice of powerplant for FLA will now be considered.

The relatively poor propulsive efficiency of turboprops at Mach numbers greater than 0.6 is demonstrated in Figure 13. Increasing cruise speed allows reductions in fleet size since aircraft productivity is improved, particularly in medium and long range applications.

Conventional turboprops do not offer sufficient sfc benefit to offset their low speed capability, except in small short range applications. Even here the turbofan is being considered because of increased passenger comfort and speed.

Propfans offer better speed capability than turboprops, combined with high efficiency. It is difficult to refute that the propfan will eventually arrive as a civil powerplant. However, its arrival will be delayed until market conditions make it economically attractive, given the high development costs necessary to bring a new engine concept into civil airline service. Against its sfc advantage over the turbofan must also be offset the installation, noise, and certification problems. These will eventually be overcome, but at present they represent a risk to civil operators. Traditionally a 7% DOC (Direct Operating Cost) advantage is required before it becomes worthwhile for manufacturers and operators to launch a new powerplant.

Figure 14 shows that fuel price has to go over 1.60$/gallon before 7% mature relative DOC is achieved, and such high fuel prices seem unlikely in the near future. If initial relative DOC is considered, the arrival of the propfan is even further away.

Aviation fuel prices over the last 20 years are shown in Figure 15 clearly showing the peak in the early 1980's and the subsequent fall to a more stable low level.

Payload/range is increased in re-engining applications with propfan powerplants due to the better fuel economy. However, the payload/range benefit would be small in typical civil propfan applications, due to shorter average stage lengths. In a new aircraft design, the propfan would be used to reduce aircraft size and cost, instead of increasing payload range. However, the low utilisation of FLA and hence the small contribution made by fuel to DOC, means that if the reduced aircraft cost is countered by increased propfan price, any economic advantage could disappear.

Turbofans as a general type cover a wide range of bypass ratio, and an attempt to determine the optimum level of bypass ratio (or more accurately, specific thrust), is made in Figure 16. Bypass ratio is not a good parameter to base such a study on, since it is influenced by core cycle, whereas specific thrust is directly related to propulsive efficiency.

Uninstalled engine sfc decreases with decreasing specific thrust, because propulsive efficiency increases. However, increasing installation drag, resulting from larger fan sizes, results in a bucket shape for installed sfc. Increasing fan size results in a larger, heavier engine, which in turn costs more. The effect of this is to shift the optimum specific thrust point to the left, if minimum engine DOC is to be obtained.

It is interesting to note that the loop shape of DOC versus specific thrust is quite shallow. Therefore, a significant shift away from optimum specific thrust implies only a small DOC penalty. Risk decreases with increased specific thrust, since that is where today's engines are positioned, although increasing fuel price would shift the optimum point to the right.

On balance, the market is opting for a specific thrust level of about 15 with a modern high-bypass turbofan engine.

It should be noted that the above picture is only true for medium/long range applications. At shorter ranges, cost and weight have more impact, moving the optimum specific thrust point further left.

ADVANTAGES OF CIVIL POWERPLANTS

Given that the FLA engine design requirements are similar to those of a civil engine, then there are powerful arguments in favour of using an existing civil engine, as listed in Figure 17.

Reliability is an important attribute for all civil engines, and an existing civil engine will have demonstrated its reliability in service. Even a new civil engine will have undergone considerable development before service introduction.

Competition is a powerful driver for any engine manufacturer to keep its products saleable. Thus competition means continuous development over the life of the engine, and engine performance will be continually improved. These improvements can usually be incorporated in the form of upgrade packages into existing engines, enabling an operator to keep engines up to date over a long period.

Economic arguments will usually point in favour of using an existing civil engine. Development costs will be spread over a large number of units, and civil contracts provide a powerful incentive for the engine manufacturer to keep to timescales. The design of the engine will be such as to minimise engine operating costs, and market forces will ensure further engine development.

Commonality of the military aircraft powerplant with civil engines allows maintenance at many external agencies, which is usually cheaper than traditional military maintenance.

Civil engine availability is summarised in Figure 18. Low bypass turbofans and turboprops have been largely superseded by high bypass turbofans and advanced turboprops. No turboprop on the market at present meets the FLA thrust requirements, so a new or developed engine would be required. Economic arguments already discussed will probably delay the introduction of contraprops and advanced ducted propellers until a large fuel price rise occurs. The civil engine market is effectively limited at present to turbofans and advanced turboprops.

POWERPLANT NUMBER

FLA could be configured as either a two, three or four engined aircraft. Figure 19 summarises the advantages and disadvantages of each option. Three engine solutions pose the major problem of combining a tail mounted engine and rear loading door. Twins have an economic advantage, but safety and operational disadvantages when one engine fails. Conversely, the four engined aircraft trades a little economy for fewer problems when an engine failure occurs.

Field performance is better with propeller powerplants and, to a lesser extent, 4 turbofans, if it is not a design parameter. Although field performance is not presently a critical factor for a FLA a change in design requirements could influence the choice of powerplant number and type.

POWERPLANT CONCLUSIONS

Powerplant options for FLA are summarised in Figure 20. The major disadvantage of the turboprop is speed, which has an economic impact when aircraft operational capability is accounted, apart from the obvious increase in flight time. As has been demonstrated, the turbofan suffers a little in fuel burn, but has no other obvious disadvantages. In contrast, the propfan has several disadvantages, notably the risks associated with it at present, and its non-availability.

The fuel economy benefits offered by the propfan in the FLA applications may make it appear to be the best powerplant choice. However, the economic advantage is eroded in FLA, given its low utilisation and the possible increased capital cost of propfans.

Given the timescale constraints imposed by the FLA programme, and the present non-availability of the propfan, a modern turbofan seems to be the most promising choice.

COMPARISON OF SOLUTIONS WITH ALTERNATIVE POWERPLANTS

General arrangements of solutions with 4 turbofans, 2 turbofans and 4 turboprops are shown on figures 21, 22 and 23 respectively. All are high wing, T tail rear loading configurations with wing mounted powerplants. Alternative configurations have been considered in the past and rejected for a variety of reasons.

The main characteristics of the solutions are compared in figure 24 together with the 4 contraprop aircraft described earlier. Results are presented for a 25 tonne maximum payload at 3.0g for the contraprop aircraft and 20 tonnes for the others. Cruise mach number is 0.65 for the turboprop aircraft; this is a realistic limit for efficient use of a conventional propeller. All the other solutions cruise at M = 0.72. The wing areas of the 4 turbofan, 2 turbofan and 4 turboprop aircraft have been driven by fuel volume requirements on a long range mission. Landing considerations fixed the wing area of the 4 contraprop aircraft. Cruise requirements have driven the powerplant size. The maximum take off power of 10400 shp quoted for the contraprop aircraft was not needed for take off performance, hence the engine was flat rated at 8800 shp.

The Operating Weight Empty (OWE) of the 2 turbofan and 4 turboprop solutions are shown to be significantly lower than the 4 turbofan solution. The 4 contraprop solution weights are not comparable with the others because of the different design payload. The Maximum Take Off Weight (MTOW) comparison shows a similar trend to that of the OWE's. The benefit of low fuel consumption of the 4 turboprop solution results in the lowest MTOW. When comparing the fuel used it is interesting to note the 2 turbofan solution has a consumption approximately half way between that of the 4 turbofan and the 4 turboprop solutions. The fuel saving offered by propellers is more pronounced for typical peacetime operations when the aircraft are generally lightly loaded and a high proportion of flight time is spent at low throttle settings. Clearly the 4 contraprop solution also offers significant fuel consumption benefits which are shown on this comparison despite the disparity in design payload.

OVERALL CONCLUSIONS

Advances in technology since the 1950's have led to major improvements to civil transport aircraft. FLA will be designed to take full advantage of available technology, including a modern powerplant and state of the art airframe, systems and avionics. Major cost savings, manpower reductions and improved capability are offered relative to old technology existing aircraft.

The turboprop and contraprop solutions of FLA offer big potential savings in fuel consumption as would be expected. The twin turbofan solution offers a significant fuel consumption advantage over 4 turbofans. Speed and hence productivity is a disadvantage for the turboprop solution. Utilisation of available civil engines is considered to be very important to an FLA programme. Contraprops now seem extremely unlikely to be fitted to a civil aircraft prior to being needed for FLA. Propeller engines of the right size also appear to be unlikely to be fitted to a civil programme before FLA.

Developed versions of existing engines may however be available.

The twin turbofan solution is likely to offer significant economic advantages relative to the four turbofan and engines of the right size are certain to be available. On the other hand any twin engined solution will suffer operational disadvantages. An engine for a four turbofan solution is likely to be available due to strong civil interest for 100 seater applications.

No firm conclusion can be drawn at this stage on the best powerplant. Trade-off studies need to be conducted to show the effects on life cycle cost and operational effectiveness.

These trade-offs will help the Air Forces to decide where to finalise their requirements. Then further, more detailed, analysis should be conducted prior to final powerplant selection.

REFERENCES

1 H. W. Bennett. Institute of Mechanical Engineers.
Aero engine development for the future.
1983. Volume 197. No.48

2 N. J. Peacock and J. R. Sadler. American Institute of Aeronautics and Astronautics.
Advanced Propulsion Systems for Large Subsonic Transports.
July 1989. AIAA-89-2477.

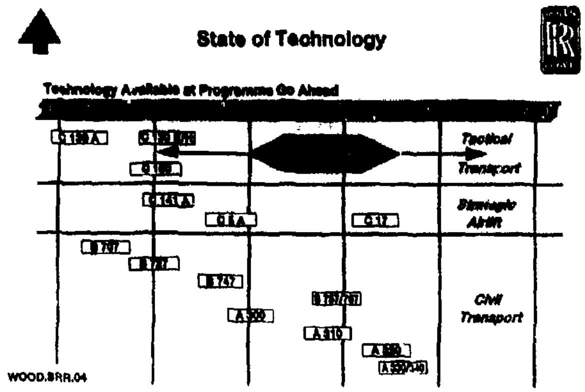


Figure 1

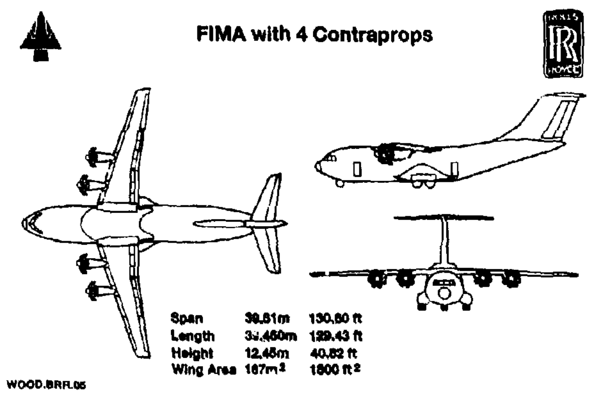
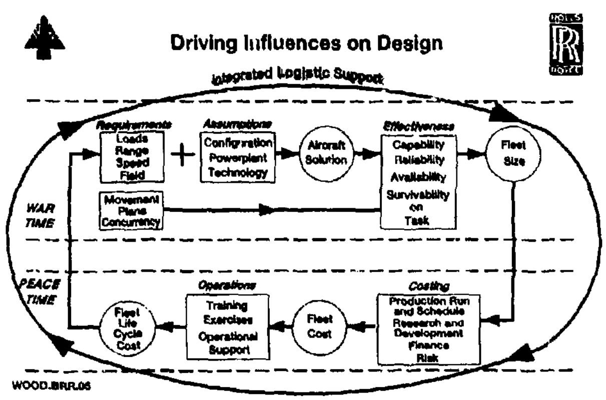


Figure 2



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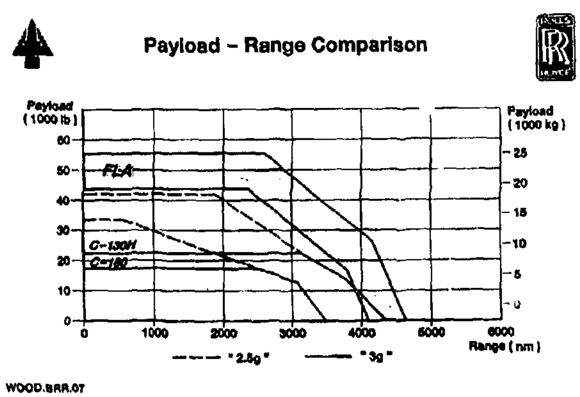

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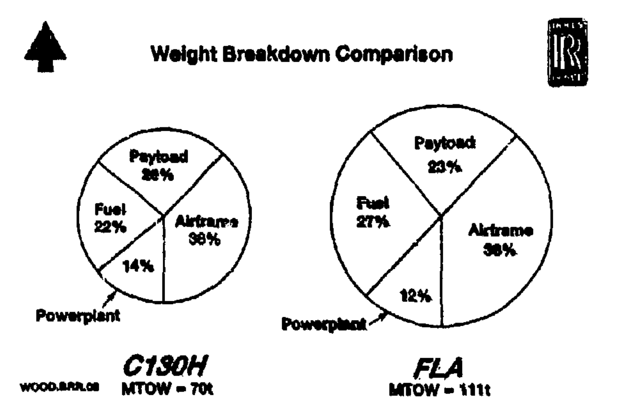
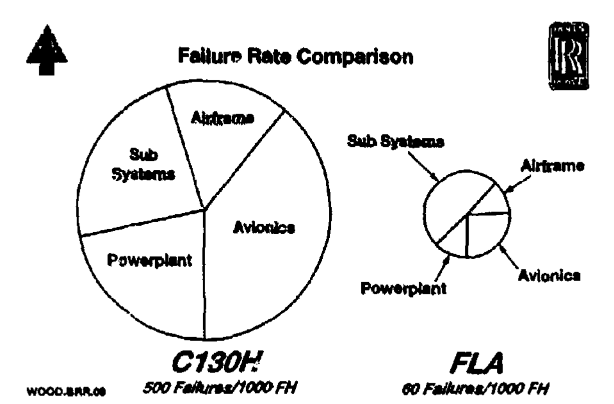


Figure 5



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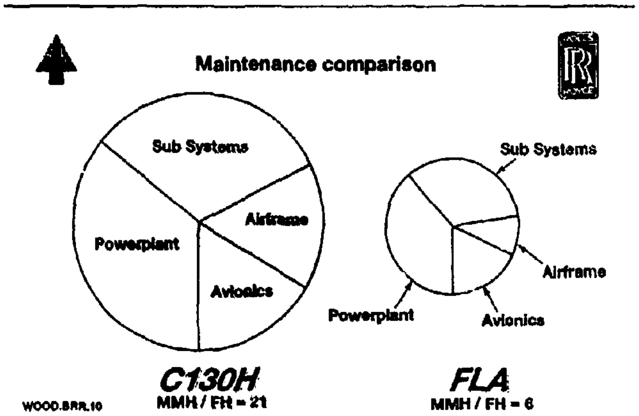

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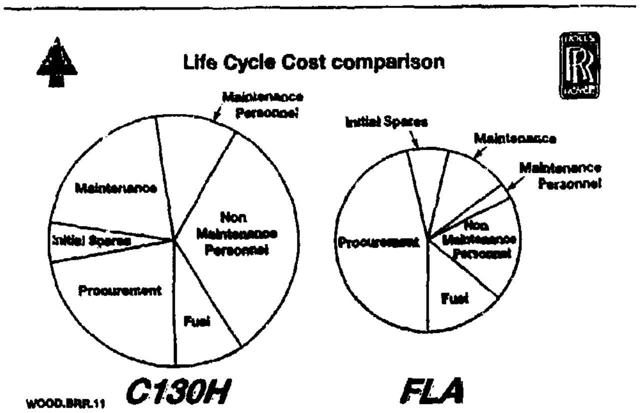

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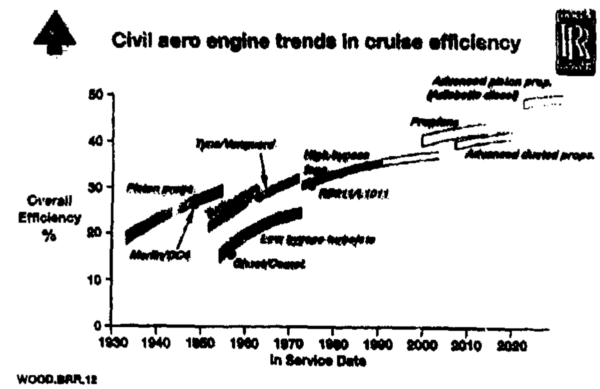

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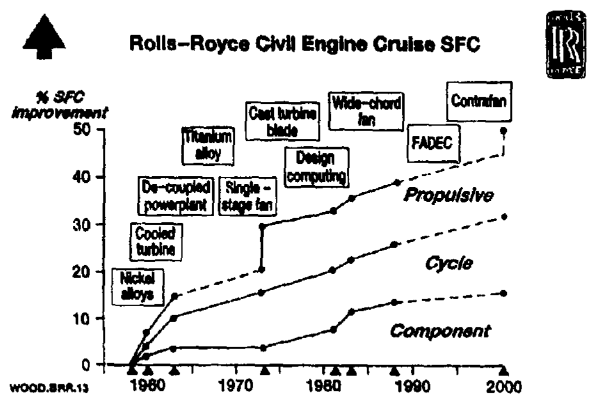
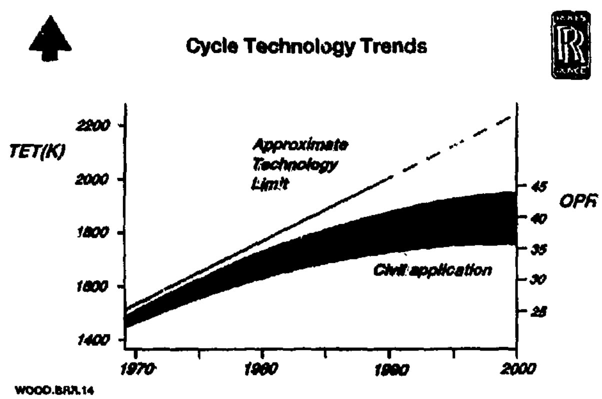


Figure 10



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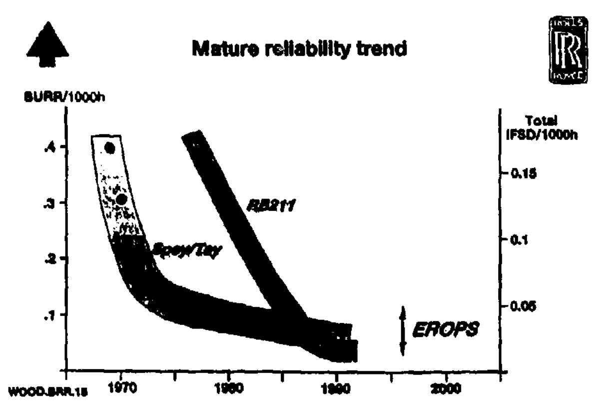

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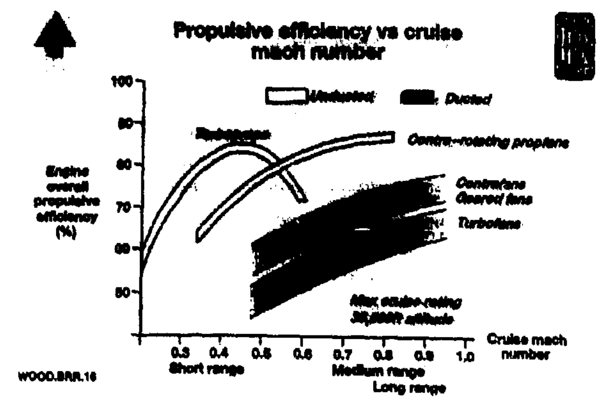

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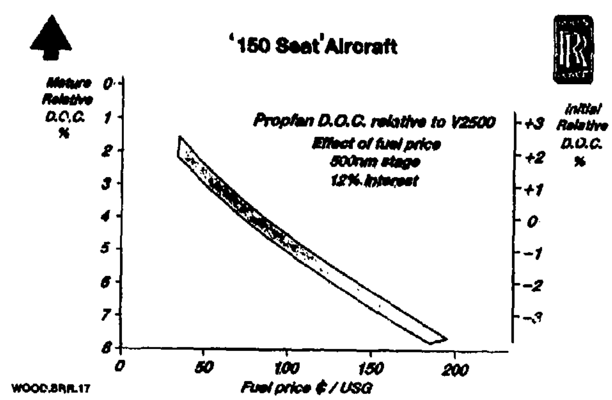

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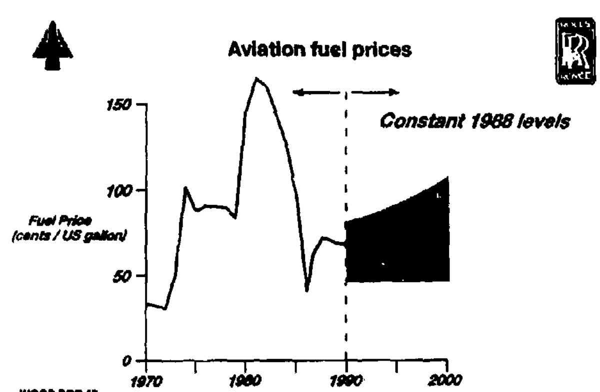

Figure 15

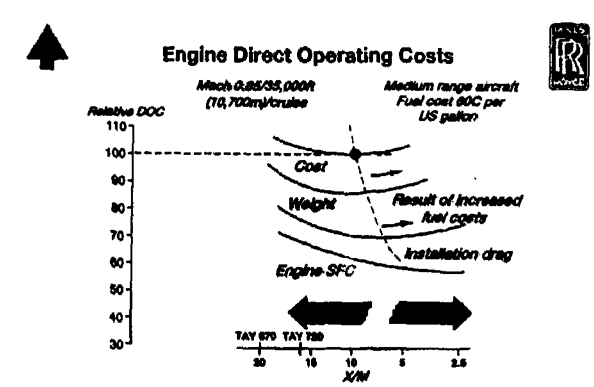

Figure 16

Advantages of Civil Engines

Reliability	*– Proven in service* *Highly developed on aircraft introduction*
Competition	*– Continuous development* *Performance improvements*
Economics	*– Cost driven design* *Engine development is market driven* *Shared development and risk*
Civil Commonality	*– Competitive outside maintenance*

FLA Engine Requirements = Civil Engine Requirements

WOOD.BRR.20

Figure 17

Civil Engine Availability

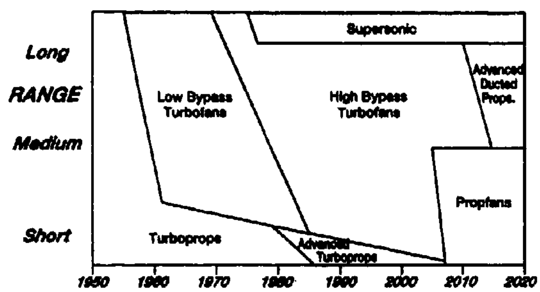

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Figure 18

Choice of Engine Number

Number of Engines	*2*	*3*	*4*
Advantage	*Economics*	*Better Safety Margin*	*Best Safety Margin*
Disadvantage	*Worst One Engine Failed Capability*	*Tail Mount Problems*	*Economics*

WOOD.BRR.22

Figure 19

Powerplant Options – Summary

	Turboprop	*Turbofan*	*Propfan*
Availability	x	✓	x
Reliability	✓	✓	–
Fuel Consumption	✓	–	✓
Speed	x	✓	✓
Maintainability	✓	✓	–
Weight	✓	✓	–
Noise	–	✓	–
Risk	✓	✓	x
Installation	–	✓	–

Key: ✓ No Problem
– Not Ideal
x Problem Exists

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Figure 20

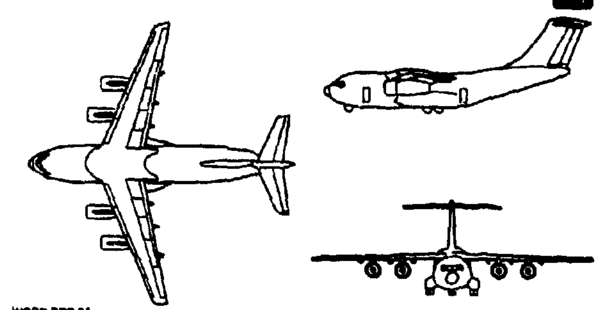

Figure 21

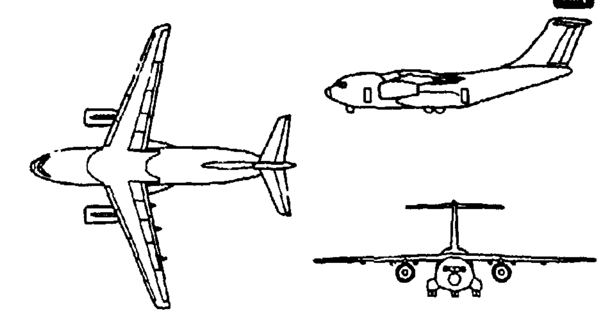

Figure 22

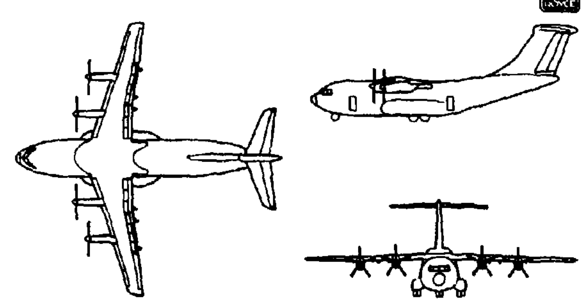

Figure 23

Comparison of FLA with alternative powerplants

Powerplant	4 Turbofans	2 Turbofans	4 Turboprops	4 Contraprops
Payload at 3.0g – t	30	30	30	25
Mach No.	0.72	0.72	0.66	0.72
Wing Area – m²	175	152	145	167
Engine Rating	19000 lbf	34000 lbf	8300 shp	10400 shp
OWE – t	49.0	43.2	43.1	53.5
MTOW – t	93.0	88.6	82.2	100.5
Fuel at MPL – t	25.9	22.4	19.1	22.0
Peacetime Fuel – t/year	2620	2080	1520	1790

WOOD.BRR.37

Figure 24

"IMPROVING MILITARY TRANSPORT AIRCRAFT THROUGH HIGHLY INTEGRATED ENGINE-WING DESIGN"

AD-P006 252

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I - ABSTRACT

Current studies have shown the interest of very large bypass ratio engines (10 < BPR < 14) to power Long Range Airliners, at cruise speed exceeding Mach 0.8. A further benefit in term of installed SFC can be expected for the Future Large Aircraft (FLA), cruising at Mach 0.75.

Compared to an equivalent turbofan, a very large bypass engine can deliver a higher thrust during take off, thus improving the high lift capability of the aircraft.

Taking into account that a conventional front fan engine is likely to show a large Radar Cross Section (RCS), and that this problem would have to be addressed for FLA, the engine preferred concept is a Ducted Aft Contrafan. The resulting high hub-tip ratio fan flow path, combined with slow rotating composite fan-blades is indeed a good approach toward reduction of the engine RCS.

In order to minimize the extra-weight due to the long duct, a highly integrated engine-wing design is proposed, offering a reduced friction drag ; a particular attention is paid to the maintenance and transportation problems. (25) * Military aircraft, * Jet transport aircraft,

II - INTRODUCTION

In the past few years, many advanced-project studies have been done for the Future Large Aircraft, and more recently within the EUROFLAG Organization . Various type of engines are considered, and specifications in term of thrust, SFC, and operational requirements are available for each type, in order to compare their merits on the base of Aircraft/Engine Life Cycle Cost.

So far, propfans and turbofans engines have been proposed by the engine manufacturers : Propfans engines are very interesting in terms of performance but much work has still to be done on "on wing" installation. Also, their physical avaibility for FLA depends on the evolution of fuel price for commercial applications. For these reasons, emphasis has been put recently on advanced commercial turbofans like the CFM 56-5C family of CFMI and their derivatives.

The CFM 56-5C2 (32 500 lbs take off thrust) is a good candidate for a twin engined FLA. Derivatives of the CFM 56-3 or refanned versions using the CFM 56-5C core are currently studied for the four engined aircraft version.

The intent of this paper is to show a "half-way approach" between turbofan (easy installation) and propfan (high thermopropulsive efficiency) concepts.

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III - CONVENTIONAL ENGINES

Conventional turbofan engines can be considered for FLA, either twin or four engined aircraft. Twin engining can be provided by two 72.3 inches fan diameter CFM 56-C2 (see Fig.1) very efficient power plants being developed for the Airbus A 340. This engine will be certificated in October 1991.

If a four engined aircraft is preferred, a CFM 56-3 type engine, derated to approximately 16 klb can be considered, should an "off the shelf" and "short" programme be required.

Other "off the shelf" engines could be candidate for FLA if a commercial 100 PAX short range aircraft is launched with a derivative or a new turbofan engine. In case of a new engine, this one would provide FLA with a better suited powerplant installation in terms of thrust level and installed SFC. SNECMA has made two preliminary design studies of new 100 PAX engines. The first one is a "performant" cycle engine, rated at 18000 lb of SLS thrust,

with a 55 "Fan diameter" ; the second one is a "low cost" but less performant cycle engine, with a 55 "Fan diameter" and also rated at 18000 lb SLS thrust.

Fig.2 and 3 show the architecture of these two study engines, called "M 123 A" and "M 123 B" which can be considered as "good conventional" engines for a four engined FLA.

Compared to the CFM 56-3 at the same thrust level, they offer between 10 and 15% of Cruise SFC saving, and 30% of weight saving.

IV - INTEREST OF VERY HIGH BY PASS RATIO ENGINES FOR FLA

A Very High By pass Ratio engine can be defined by its By Pass Ratio (B.P.R. = $\frac{\text{Secondary mass flow}}{\text{Primary mass flow}}$, of a value located between the ones of a Conventional Engine (BPR = 6 typically) and a Propfan Engine (BPR = 35 typically).

Fig.4 shows a potential <u>12 % Specific Fuel Consumption</u> (SFC) <u>saving</u> offered by a Very High By Pass Ratio engine (Engine B ; BPR = 15 typically) over a Conventional Engine (CFM 56 -5C) at a 35 Kft Mach 0.75 cruise speed. This improvement is due (at a given technology level) to the <u>increase in propulsive efficiency</u> provided by the higher BPR . But one must take good care that this saving is not totally offset by the fact that the nacelle of Engine B , being 1,5 times bigger than the CFM 56 -5C one, will be heavier and provide more drag. In order to minimize this drawback, SNECMA have studied a <u>highly integrated engine/wing</u> installation which will be described later, resulting in a project called "<u>M 110</u>", based on the CFM 56-5C core engine, whose main characteristics are given in Fig.5, compared to the CFM 56 -5C, at 35 kft -0.8 Mach number.

The highly integrated design allows <u>an attractive 8,7 % cruise SFC saving</u> over the CFM 56 -5C, taking into account the nacelle weight effects on SFC (0,7%) and also the increase in nacelle/wing interaction drag (1,3%) on SFC. This saving would be increased by approximately 1.5% when cruising at 0.76 Mach number.

Another interesting feature of a very large by-pass ratio engine for FLA is its ability to <u>procure more thrust</u> than a conventional engine <u>between Mach 0 and Mach 0.25</u> (take off speed). This feature can enhance the <u>short take off capability of the aircraft</u>.

V - FROM CONVENTIONAL TO HIGHLY INTEGRATED INSTALLATION

A Conventional (pod) installation suits conventional engines well, but Very High By Pass engines are not conventional engines ! Due to the big size of their fan, they need some device in order to minimize the number of low pressure turbine and booster stages. Fig.6 shows the various configurations : "M 109", geared front fan ; "M 109 CR", geared front contrafan, "M 110", direct drive aft contrafan. The studies are today in favour or a "M 110" configuration, which offers a bonus of 2,0 % SFC over the geared configuration (gear and heat exchanger create losses), and thus "pays" its extra weight (500 lb over the M 109) at an exchange rate of 0,6 % SFC per 2200 lb of dead weight.

Installing the "M 110" concept under a wing has given risu to two main concerns shown on Fig.7 : Access to fan and core, and the ground-clearance.

Fig.8 and 9 show that, thanks to the very low tip speed - (200 M/S) of the direct drive contrafan, which results in low energy containment, the fan cowl can be designed to be opened, giving direct access to the fan and the core in a way which is even better than the today situation. This concept (patented) is referred below as "Fan Cowl Opening" concept.

A further step is achieved (see Fig.10), in order to reduce drag and weight, by integrating the upper part of the nacelle into the wing. By doing so, the ground clearance is increased significantly.

The studies have shown that the resulting weight saving is equivalent to the weight of the pylon of a conventional engine (600 kg).

VI - ENGINE TRANSPORTATION

"Big fan" engines are a headache for transportation.
Fig. 11 and 12 show the different steps for engine removal with the "Fan cowl opening" concept.
It can be noted that the resulting volume and weight being carried are the ones of the core and the power turbine, plus the ones of the disassembled fan blades. They constitute a smaller volume comparing to what is carried today when a conventional engine of the same thrust is removed from the wing.

In conclusion, such an integrated design benefits to the performance of the "M110" concept, as said in paragraph III, and provides easier maintenance and smaller volume and weight for engine transportation. This latter advantage is probably significant in military operations, and could justify further studies.

VII - INTEREST OF AN INTEGRATED DESIGN FOR THE REDUCTION OF THE ENGINE FRONT RADAR CROSS SECTION

Future Large Aircraft existing requirements do not ask for any particular Radar Cross Section (R.C.S.) protection.

Obviously, a Military Transport Aircraft of conventional design is easily detected, due to its large dimensions.
Nevertheless, should special absorbant materials be used for the airplane surface, the size of the fans (or propellers) of to day large bypass engines make them easy to identify, especially from the front -(Counting the number of fan blades is a common radar performance).

SNECMA have looked at the possibility of reducing significantly the RCS of a large by-pass ratio turbofan.
A computer model has been made (see Fig.13) simulating two rows of blades and the inner and outer walls of a turbofan.

By varying the L/H ratio and by making the back stream row of blades rotate or not, one can simulate in a simple way, a turbofan (L/H = 0,5) with back stream row of blades not rotating, an aft contrafan (L/H = 2) with back stream row contrarotating, or a propfan (L/H < 0,1) with contrarotation.

With no absorbant material on the shrouds, Fig.14 shows the resulting signature diagrams when comparing the three types of engines.

The highest signature at 0° bearing angle is for the turbofan, and the lowest is for the propfan, the contrafan being in between. No correction has been made for the fact that the propfan engine would be of a bigger diameter than turbofan or contrafan engines of the same thrust, and then would actually rank worse.

Due to the fact that a propfan is a not shrouded engine, the only way to reduce its RCS would be to use absorbant material on the blades. We have not looked at this design so far, because it is difficult to combine tensile resistance, stiffness and radar absorbant properties in a single composite material.

We have made some calculation on the turbofan and the contrafan engines, assuming that the shrouds would be treated with absorbant materials. The results are given on Fig.15. They show that reductions in RCS signature can be obtained with shroud treatments, providing that L/H is sufficiently high. According to this figure, -L/H = 5 gives a very important reduction in RCS. The result on the design is a much longer inlet duct than usual. A cross section of the "M110" concept with RCS treatment is shown on Fig.16, in an integrated engine/wing design. This type of nacelle is also well suited for noise treatment and will provide the aircraft a remarquable low noise operation.

As far as the design is concerned, the long inlet duct is more acceptable on the "M110" direct drive after fan concept, than it would be on a front fan concept where the over-hung inlet would add more weight and loads in the mounting system as shown on Fig.17.

In conclusion, if a requirement is set on the RCS of FLA engines, we think that their RCS signature can be greatly decreased with a highly integrated engine/wing design of the type of the "M110" concept, using a longer inlet duct treated with absorbant radar materials. This arrangement would also provide FLA with outstanding low noise operation.

VIII - "LOW RCS","M110" ENGINE CONCEPT

As said above, high integration to the wing of very high by-pass engines is essential to take the best of the increase in bypass ratio.

As shown in paragraphs V and VI the "Fan-Cowl"Opening" concept allows excellent maintenance access, and easy engine removal together with smaller volume and weight to be transported than existing engines.

Fig.18, shows a possible arrangement on a FLA wing at cruise mode.

Fig.19 is a cross section showing the integrated engine and the hypersustentation flaps at engine exit during take off mode.

Fig.20 shows the reverse mode, with flaps extended and spoilers deployed. The reverse is of the A 320/CFM 56 target doors type, with three 120° apart doors, one at the top, at a spoiler location, and two on each back end of the "Fan Opening Cowls".

IX - CONCLUSION

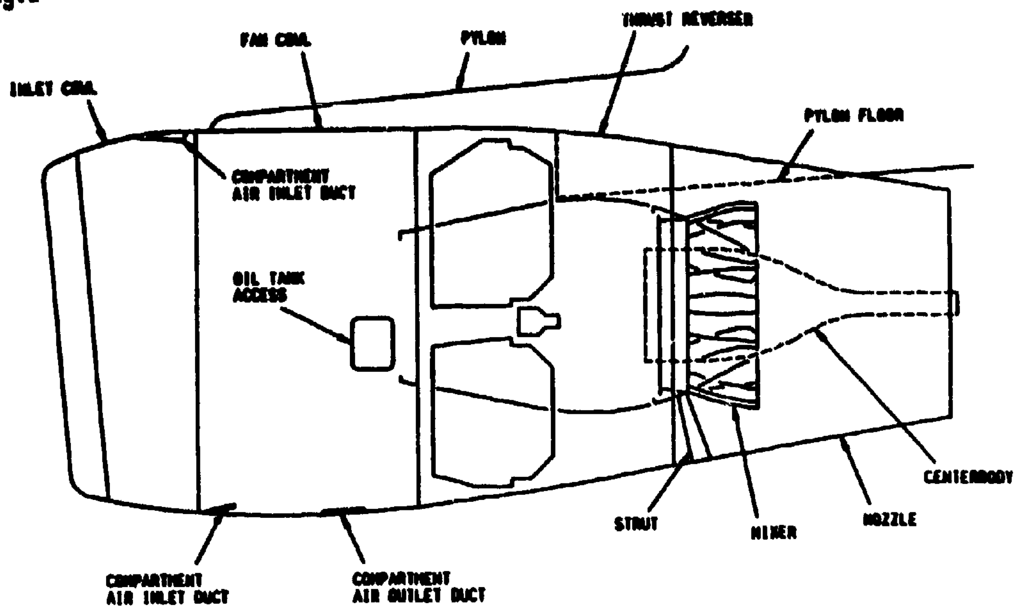
Conventional turbofan engines are candidate to power the Future Large Aircraft, either the CFM 56- 5C2 (twin) or a CFM 56 -3 derivative (four).

If a Commercial 100 Pax Aircraft is launched, a "New Conventional" engine could also fill both the Commercial and FLA specifications ; the 55" Fan diameter "M123" project is the SNECMA approach to this question.

A new design (not conventional) can be envisaged, taking benefit of the CFM 56-5 core :

- A Very High Bypass Ratio (typically 14) would increase cruise performance, providing that the nacelle is highly integrated to the wing and that the fan is directly driven (no gear and heat exchanger losses). Thrust is increased during take off for the benefit of short take off.
- A long inlet duct would provide, with proper treatment, a significant decrease in Radar Cross Section, making the engine more difficult to identify. Accordingly, the aircraft would have a remarquable low noise operation.
- These features are found in the "M110" after contrarotating very high bypass turbofan project. A special attention has been paid to the maintenance access to the core and to the transportation problem. The resulting "Fan Cowl Opening" design looks very promising to reduce the size and the weight of the transported engine, and could be of interest in military operations.

Fig.1



A340/CFM56-5 NACELLE

Fig.2

M123 A
Long Duct Mixed Flow

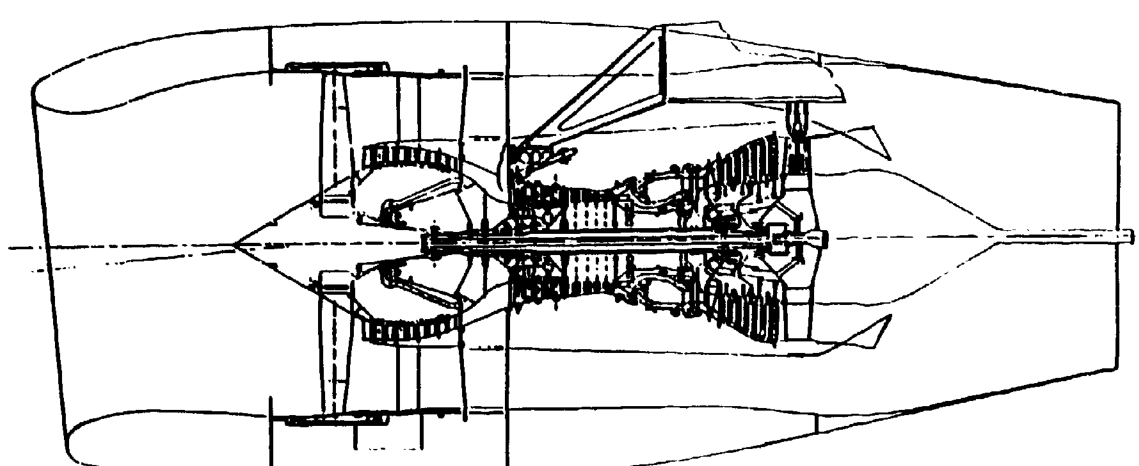


Fig.3

M123 B

Low Cost ENGINE

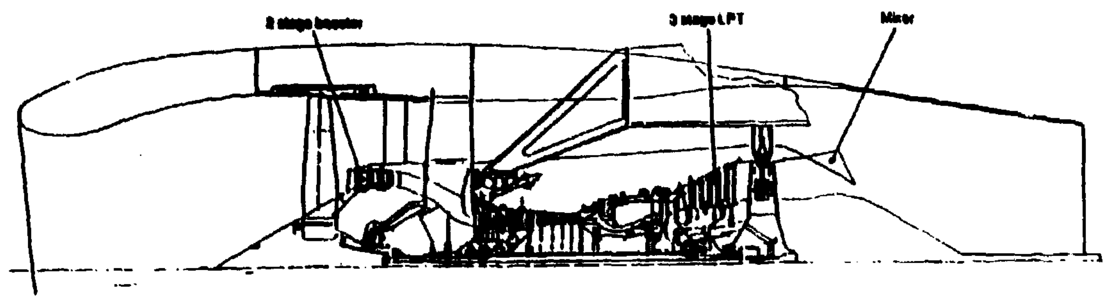
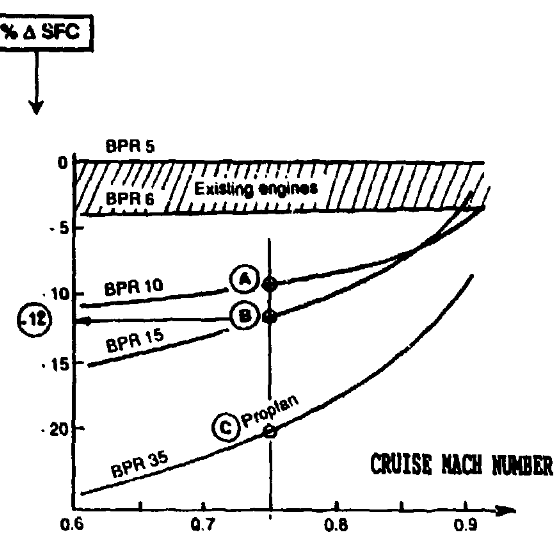


Fig.4

	Fan diameter
Existing CFM56-5C (Base)	Base
Engine (A)	x 1.25
Engine (B)	x 1.5
Engine (C)	x 2.2



UBE engines are good candidates for "Under the wing" installation

Fig.5 ADVANCED PROPULSION SYSTEM CONFIGURATIONS

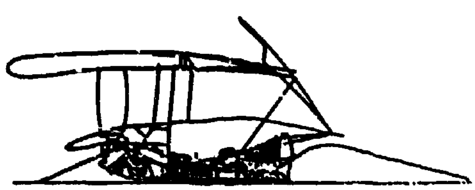
- All these studies carried out with CFM56-5 core generator

Configuration	CFM56-5C	M 109 Geared front fan	M 109 CR Geared front contra fan	M 110 Direct drive aft contra fan
By pass ratio	6.3	14	14	14
Fan pressure ratio	1.7	1.35	1.35	1.35
Overall pressure ratio	37	39	39	39
SFC uninstalled	Base	- 8.2 %	- 8.3 %	- 10.9 %
SFC installed*	Base	- 5 %	- 4.7 %	- 6.7 %

* - Wing nacelle interaction effect
- Nacelle size effect
- Weight effect

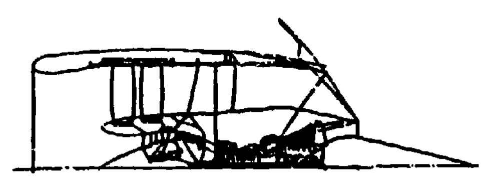
35 Kft ; 0.8 Mn CRUISE

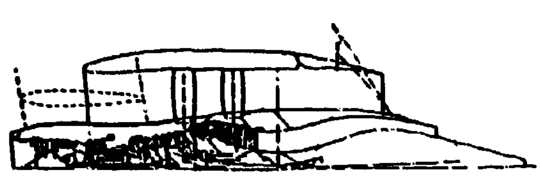
Fig.6 ADVANCED PROPULSION SYSTEM CONFIGURATIONS



M109
Geared front fan

M109 CR
Geared front contra fan





M110
Direct drive aft contra fan

Fig.7

M 110 FORMER ARRANGEMENT
Main concerns

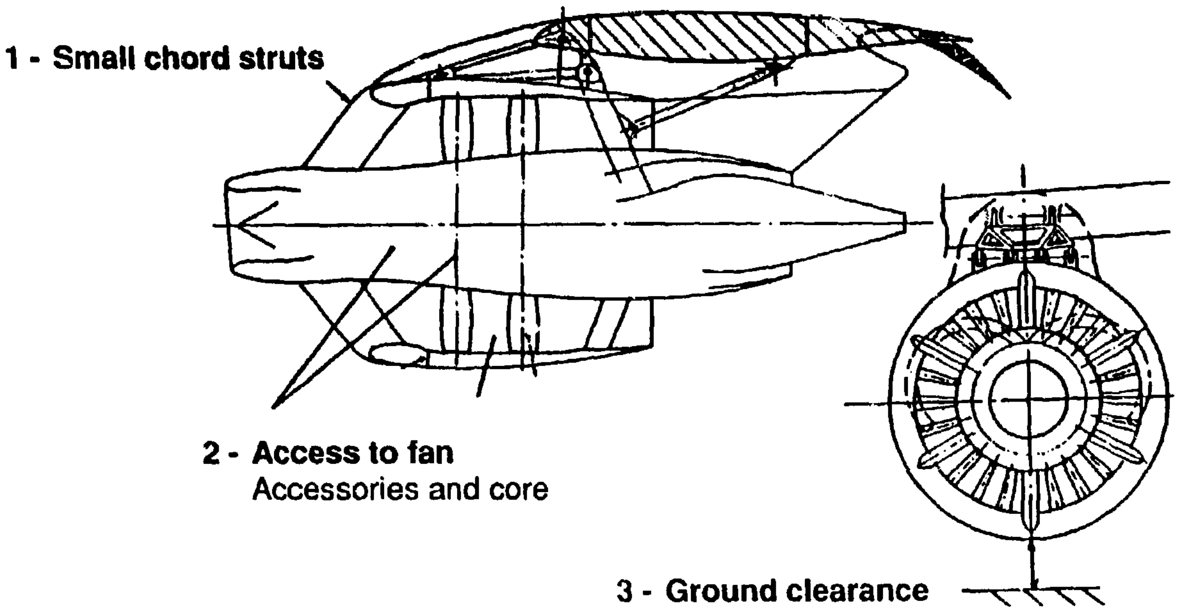


Fig.8

M 110 ARRANGEMENT
Mounting system

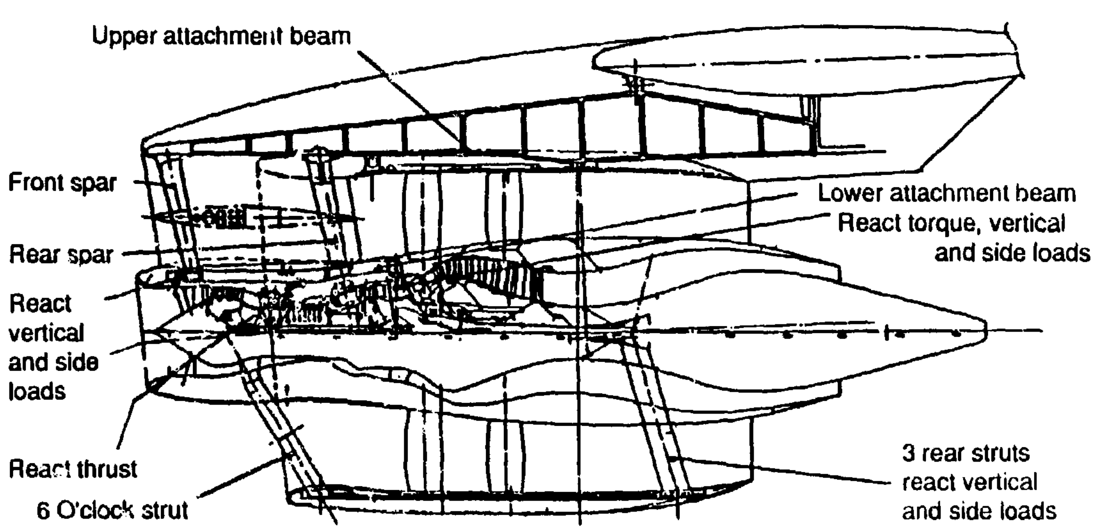
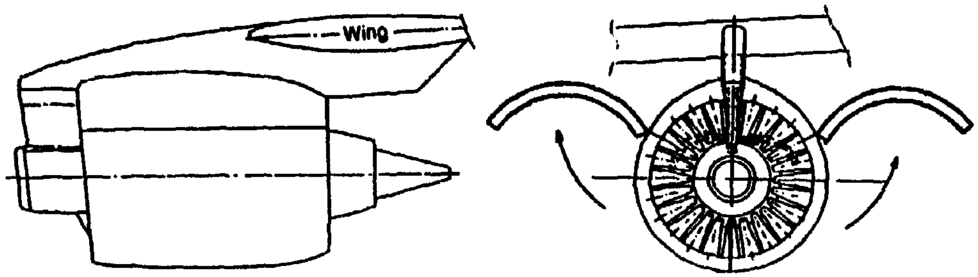


Fig.9

M 110 ARRANGEMENT
Fan and core maintenance



Opening cowls allows for :
- Borescope access
- Blade removal
- Servicing

Nota :

Fan cowl opening (patented) is permitted because of low circumferential speed (200 M/S) of contra rotating fan.

Fig.10

M 110 ARRANGEMENT
Advanced installation concept

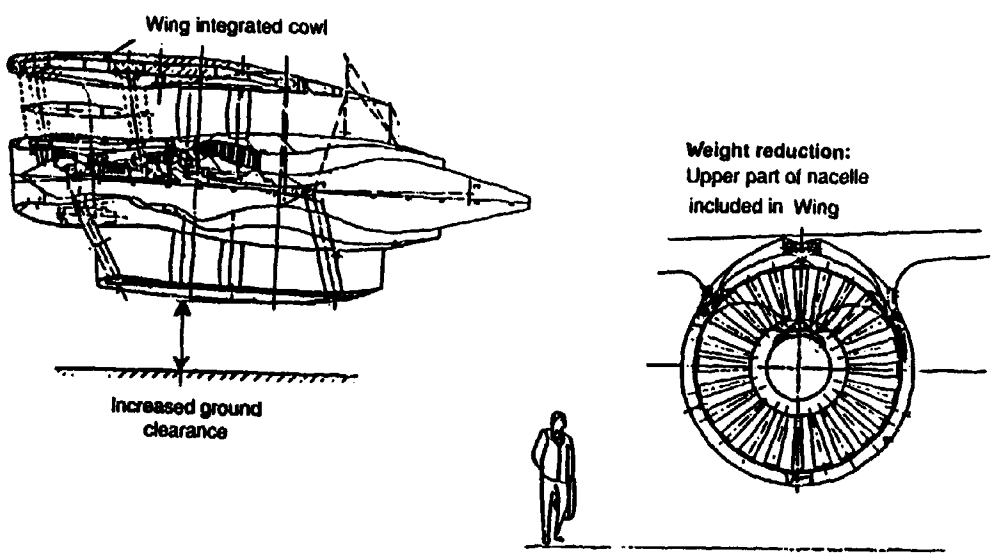
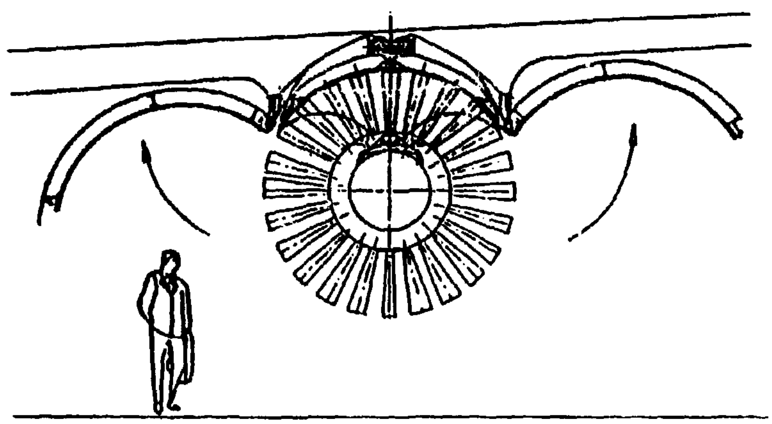


Fig.11

M 110 ARRANGEMENT
Maintenance study

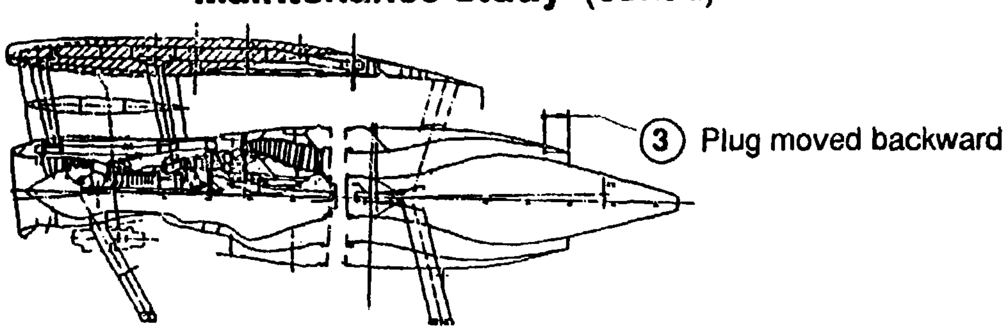


(1) Cowls opening

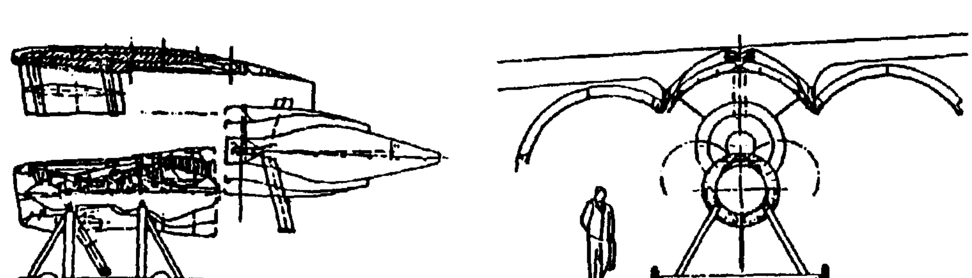
M 110 ARRANGEMENT

Fig.12

Maintenance study (cont'd)



(2) Fan blades removed



(4) Engine down

Fig.13 RCS COMPUTER MODEL

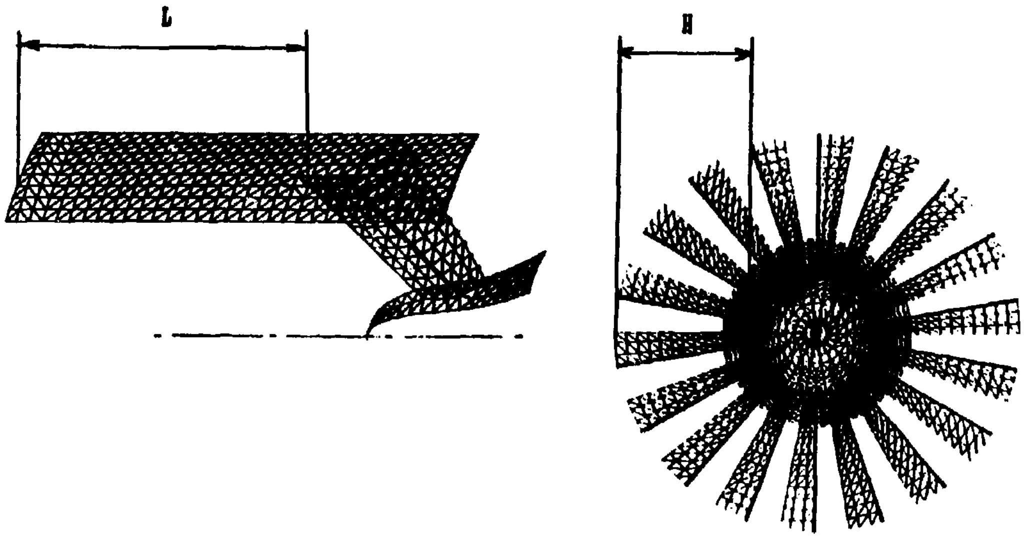


Fig.14 . COMPARISON BETWEEN DIFFERENT CONCEPTS(UNCOATED)

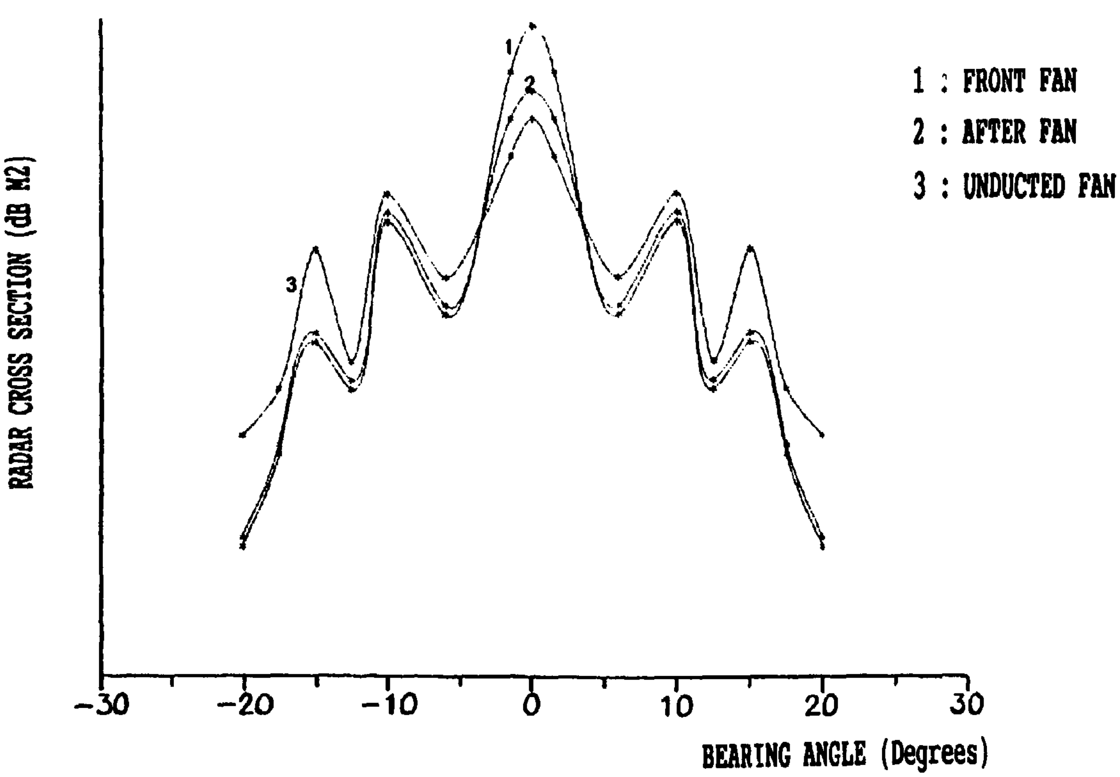


Fig.15 COMPARISON BETWEEN SURFACE COATING EFFICIENCY

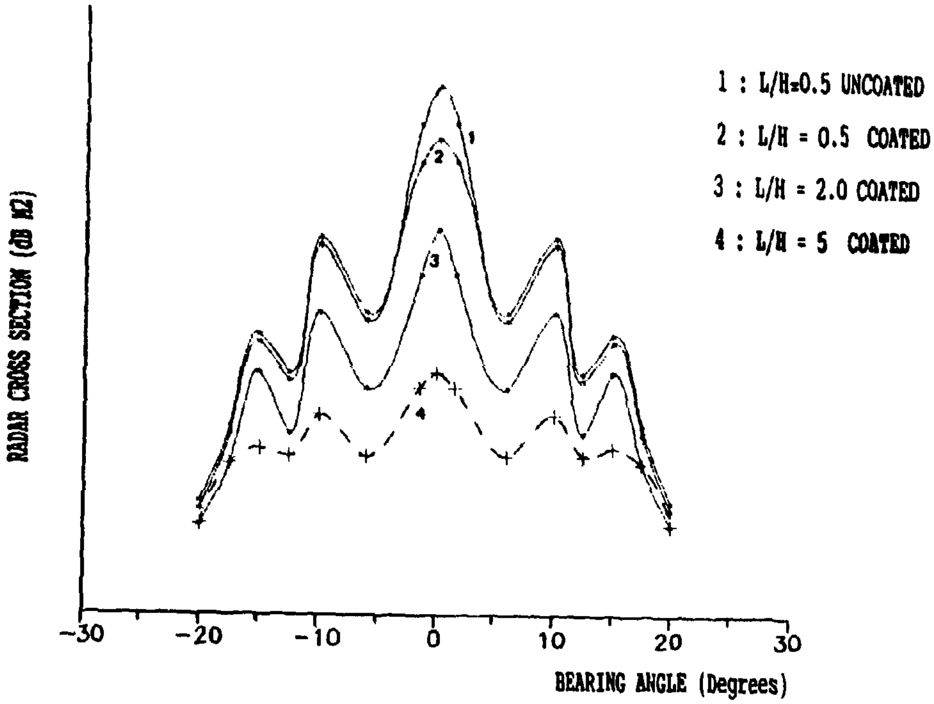


Fig.16 LOW RCS "M110". ENGINE-WING ARRANGEMENT.

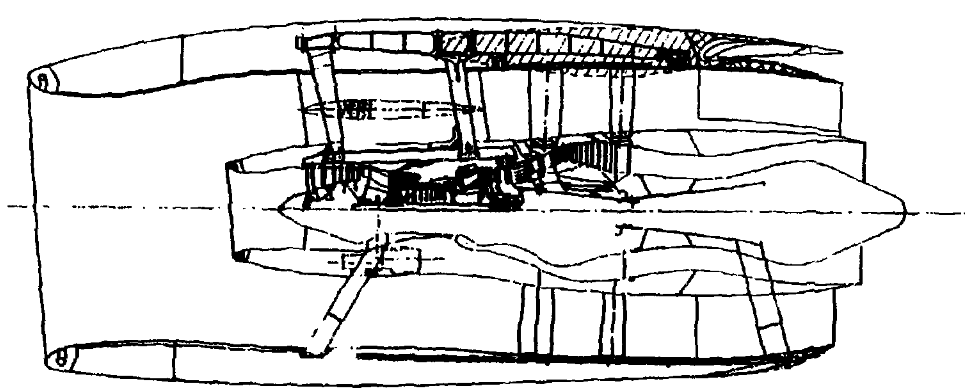


Fig.17 LOW RCS ENGINE - LONG DUCT NACELLE

Mounting (M) and Nacelle (N) loads

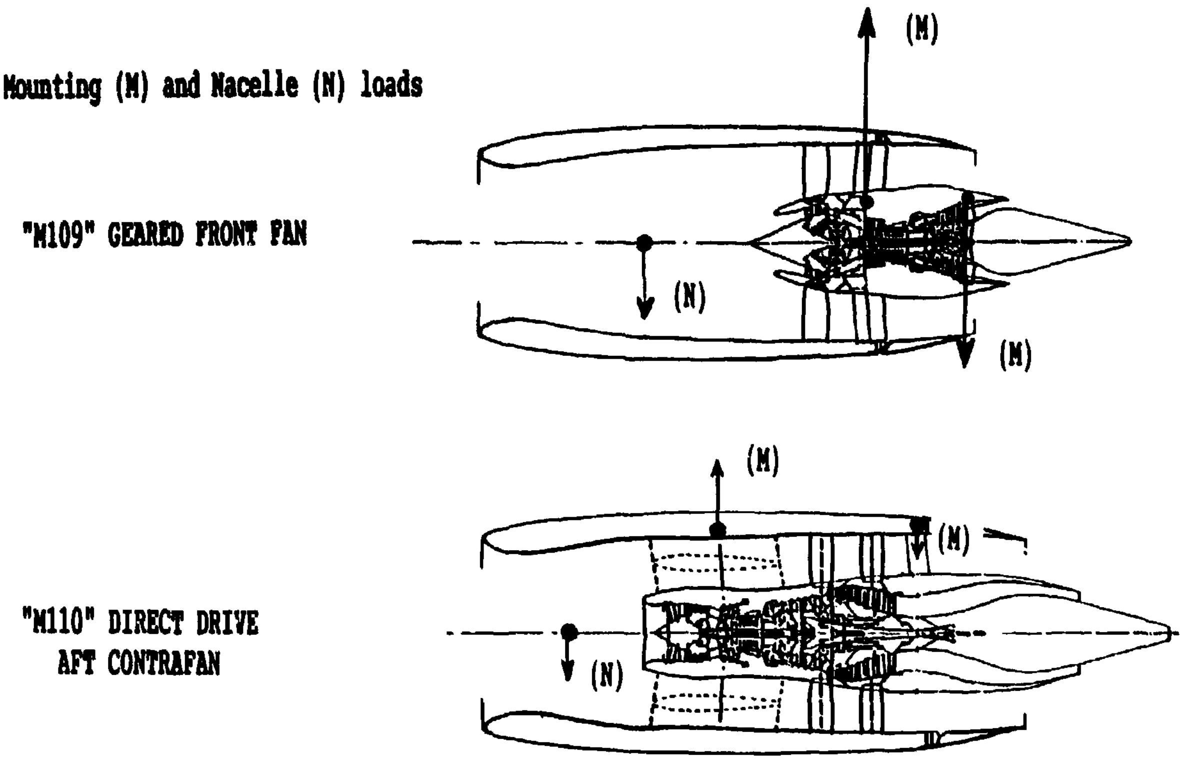


Fig.18 LOW RCS "M110" - ENGINE - CRUISE MODE.

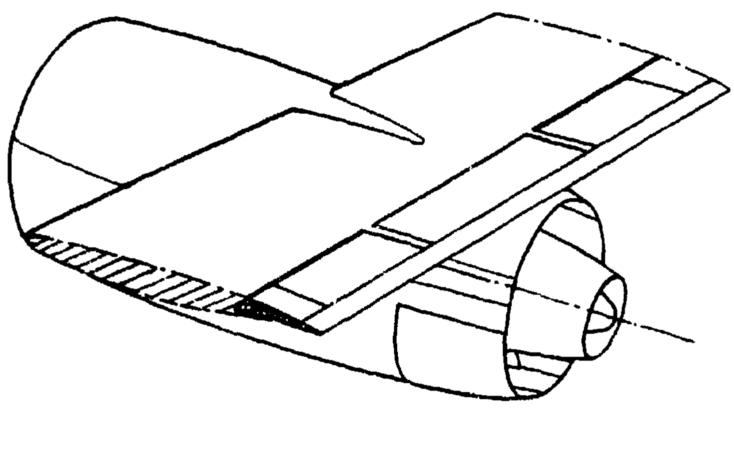


Fig.19 LOW RCS "M110" - ENGINE - TAKE OFF MODE.

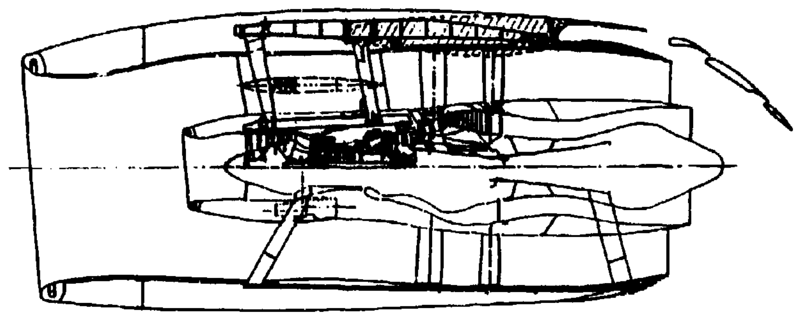
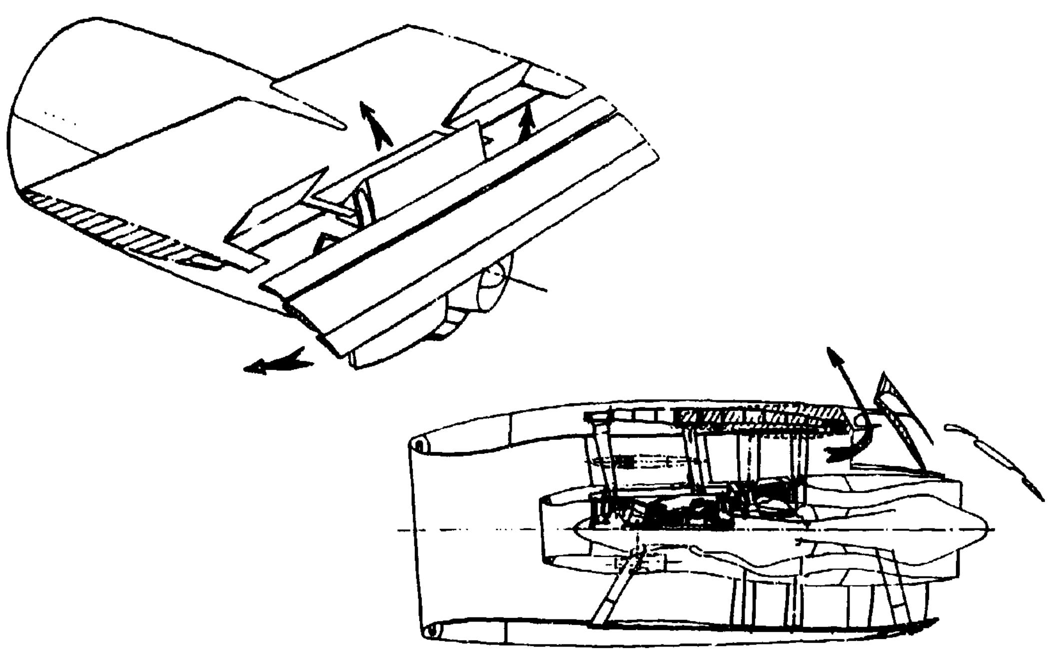


Fig.20 LOW RCS "M110" - REVERSE MODE.



AD-P006 253

THE DEVELOPMENT OF VERY THICK MULTI-FOIL WINGS FOR HIGH SPEED, POWERED LIFT TRANSPORT AIRCRAFT APPLICATIONS

by

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SUMMARY

Motivation for the development of high speed multi-foil wings began with the Boeing Canada, de Havilland Division Powered Lift Augmentor-Wing Research Aircraft of the 1970s. This was a low speed, Ultra-Short Takeoff and Landing (USTOL) demonstrator aircraft program, which used a blown ejector (multi-foil) flap at the trailing edge of a high aspect ratio wing to provide supercirculation lift with a significant augmentation of thrust (effective reduction of drag).

While the initial goal for the development of the multi-foil section was to simplify the aerodynamic/propulsion systems integration of the powered lift system for high speed flight, several aerodynamic advantages also accrued relating to the powerful control of form drag exhibited by the section.

The paper briefly discusses the theoretical development of multi-foils between 18% and 30% thickness/chord and presents results from high Reynolds number, high speed, two-dimensional and three-dimensional tunnel tests on foils up to 24% thickness/chord ratio. Both blown and unblown characteristics of the foils are reviewed.

The integration of these multi-foil sections into high speed advanced USTOL transport aircraft studies using the ejector flap concept has led to the potential for very efficient cruising transport aircraft with USTOL capability using only the thrust required for cruise.

Finally, several other potential applications for thick multi-foil sections are briefly discussed. (25) * Wings,
* Jet transport aircraft, * Short takeoff aircraft.

LIST OF SYMBOLS AND ABBREVIATIONS *

2-D	two-dimensional
3-D	three-dimensional
α	angle of attack
$C_{D_{EFF}}$	effective drag coefficient of a blown section
C_{D_o}	profile drag coefficient of an unblown section
C_{D_W}, $C_{D_{WAKE}}$	drag-minus-thrust coefficient of a blown foil, or profile drag coefficient of an unblown foil measured by the wake rake technique
$C_{D_{Wc}}$	wake rake thrust-minus-drag coefficient corrected for externally injected mass flow
C_f/c	flap/chord ratio
C_{J_N}	nozzle thrust coefficient alone (i.e. measured without shrouds or flaps)
C_L	lift coefficient
C_{L_D}	design lift coefficient

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$C_{L_{max}}$	maximum lift coefficient
cts	drag counts (0.0001 units)
$\Delta C_{D_{EFF}} / C_{J_N}$	effective drag reduction due to blowing
ΔC_L	increment of lift coefficient
δ_f	flap angle
DGW	design gross weight
ΔM_D	increment of drag rise Mach number
θ_N	engine exhaust deflection
$k\ (= \pi A\ C_{D_i} / C_L^2)$	induced drag coefficient
$k\ (= \pi A\ \partial C_D / \partial C_L^2)$	induced drag coefficient
M	Mach number
M_D	drag rise Mach number
NLF	natural laminar flow
NPR	nozzle pressure ratio
psf	pounds per square foot
q	dynamic head (in psf)
Re	Reynolds number
RMS	root mean squared
t/c	thickness/chord ratio
T/W	thrust/weight ratio
ϕ	thrust augmentation ratio $(C_{J_{MEAS}} / C_{J_N})$

INTRODUCTION

The de Havilland Division of Boeing of Canada Ltd., has been in the forefront of short range, ultra-short takeoff and landing (USTOL) aircraft development, both military and civil, since the late 1940s. Examples are the DHC Beaver, Otter, Caribou and Buffalo military aircraft and the Twin Otter and Dash 7 civil aircraft (Figures 1 and 2). These aircraft can be categorized as having field lengths, to and from a fifty foot barrier, of 1000-2000 feet.

In the late 1950s, it was recognized that high cruising speed would be key to the viability of medium to long range aircraft and that the large aerodynamic surfaces typical of short range STOL aircraft would be an impediment to efficient, i.e. low installed thrust-to-weight, high speed cruise. Conversely, to achieve STOL or USTOL performance with the smaller aerodynamic surfaces of the then-developing high speed jet aircraft, it was realized that engine thrust would need to be integrated efficiently with the aerodynamics to contribute to the lift.

In the early 1960s, de Havilland began research in the integration of thrust from jet or turbofan powerplants with the aircraft aerodynamics to augment the wing lift for both USTOL and STOVL (Short Takeoff and Vertical Landing) applications. Among several concepts studied, the integration of ejector technology has occupied a significant portion of our attention, for the many reasons well documented previously

(References 1 and 2). The research has led, over the past twenty years, to the development of the Augmentor-Wing Research Aircraft (Figure 3), a low speed USTOL demonstration program, and a full scale model of a proposed ejector lift/vectored thrust STOVL combat aircraft (Figure 4) for test in the NASA, Ames large scale facilities in California.

One area of the research that has received little publication over the years is that of the integration of ejector technology into a flap system at the trailing edge of a high aspect ratio wing for high speed flight. This was first reported in 1977 (Reference 3) as the transonic multi-foil augmentor-wing. The multi-foil system (Figure 5) was proposed to eliminate the many complexities inherent in an ejector system that is required to close up to form a single, conventional transonic foil for cruise (Figure 6), as discussed in Reference 3.

This paper has been prepared to show the development of these high speed multi-foils over the intervening years. The data are more well defined now, as a result of our later work, allowing the potential systems, structures and aerodynamic advantages claimed in Reference 3 to accrue to the concept. At the same time, the multi-foil development has been advanced.

VERY THICK, HIGH SPEED MULTI-FOIL SECTIONS

At the time of our earlier presentation on multi-foil sections in 1977 (Reference 3), a "thick" foil was considered to be in the range of 18% thickness/chord ratio, with camber to give design lift coefficients of the order of C_{L_D} = 0.35 to 0.4. These foil designs would be suitable for aircraft wing loadings of the order of 70-80 psf (342-391 kg/m^2) at the speeds and altitudes considered. Following the success of the earlier studies, and noting the powerful control of form drag with the concept (Figure 7), it became evident that even thicker foils could be considered, 24% to 30% thickness/chord, and camber to give design lift coefficients of C_{L_D} = 0.6 and higher. Foils of this level of design lift coefficient would be appropriate for aircraft wing loadings of 100-120 psf (488-586 kg/m^2). This jump in foil performance has been taken in two steps, first, the increase in design C_{L_D} to 0.6 at t/c = 18%, and then, a "half way" jump in thickness/chord between 18% and 30%, to t/c = 24% (Figure 8).

A brief description of the theoretical approach will follow directly; a more complete description can be found in the various references.

Typical experimental data will be presented on the two-dimensional tunnel testing to highlight the multi-foil characteristics. Three-dimensional, reflection plane balance data for the 18% thick foil with a design lift coefficient C_{L_D} = 0.35 will be shown, which qualifies the wake rake technique used in the two-dimensional testing for high speed drag measurements, both blown and unblown. Finally, three-dimensional, reflection plane tests of a 20 degree swept wing model, incorporating the 24% thick section with a design lift coefficient of C_{L_D} = 0.6, will be reviewed.

It should be noted that the experimental results to-date do not reflect foils developed with our latest theoretical methods. These more recent methods allow a better prediction of the flow characteristics within the intakes which will yield improvements to both the unblown and blown multi-foil characteristics. These potential improvements will be discussed.

Note that the design of the section shapes in the vicinity of the main foil trailing edge were constrained by a requirement to be able to deflect the two shrouds collectively, in the manner of a flap, through 60 degrees of deflection. Blowing flow from a nozzle or nozzles in the trailing edge of the main foil between the shrouds would Coanda around the lower shroud upper surface to augment the flap effectiveness.

THEORETICAL APPROACH

Subcritical Method

The approach to the development of these multi-foil geometries is through the use of a subcritical method using classical corrections for compressibility. The theory centres around the use of standard surface singularity potential flow solutions such as Douglas-Neumann, extending the method to compressible flow by applying the Goethert transformation to the foil geometry. The resulting incompressible flow velocities around this analogous foil are then used to compute the compressible velocities using appropriate compressible rules such as developed by Wilby (Reference 4) and Labrujere (Reference 5). In fact, the best correlation with experimental "crest" surface pressures was achieved with the Glauert correction for thin airfoils, rather than corrections more applicable to thicker foils with thicker boundary layers such as Van Dyke, or Karman-Tsien. This was our first indication that the multi-foil section appeared to behave like a thin foil i.e. with thin boundary layers, due to its control of main foil form drag (Figure 7). A surface slope correction due to Kuchemann & Weber, as used in Wilby and Labrujere, was also required to give good leading edge surface pressure correlation.

Boundary layers were initially modelled by direct superposition of the displacement thickness on to the airfoil surface. This has been improved lately by a transpiration flow method where the displacement surface is modelled by specifying a flow through the airfoil surface. This transpiration approach eliminates the potential flow calculations for each boundary layer iteration, since it becomes a vector multiplication of the influence coefficient matrix, and thus only one matrix inversion is required for each case.

Difficulty was experienced, initially, in correlating the surface pressure distributions within the intake passages to the shrouds of the multi-foil, until it was recognized that "analogous" duct geometries "in the 'y' axis", within the passages, would also be required. It was found that this could be closely approximated by a direct shift of the two trailing foils towards the main foil (Reference 7).

More recently, a method has been developed which combines compressible flow within a duct due to Lieblin and Stockman (Reference 8) with its counterpart for external flow due to Dietrich, Oehler and Stockman (Reference 9), and a surface slope correction to velocity similar to

Kuchemann and Weber. This new approach provides even better correlation of pressures around the foils (References 10 and 11). The method also uses the transpiration approach to model the boundary layer. A typical correlation is presented in Figure 9 for the 24% thickness/chord foil WT-CT. The attraction of this most recent method is that solutions are based on incompressible flow calculations about an untransformed airfoil as its basic solution, and the method of superposition can be used to obtain solutions at, for example, other angles of attack. The calculations for multiple Mach numbers can be evaluated also from the one basic case.

Supercritical Methods

The computational aerodynamics group at NASA, Ames have applied limited resources to modifying an existing two-dimensional, full potential finite difference method to calculate transonic flow about the multi-foil sections (References 12 and 13). The method still needs improvement (see discussion in Reference 10), however, it is extremely expensive to run a single case and is not yet considered to be a production code.

EXPERIMENTAL RESULTS

General Comments

All of the multi-foil sections shown in Figure 8 were tested two-dimensionally in the National Aeronautical Establishment (NAE) 60 inch x 15 inch transonic facility at Uplands, Ottawa, Canada. Lift and pitching moment were measured on the tunnel balance, and calculated from pressure integrations. Drag was determined by a four-probe (spanwise) wake rake method. The wake rake technique has been very carefully developed by the NAE staff to measure both drag and thrust of wakes and jets and includes corrections for blown configurations to account for significant externally supplied blowing mass flow, injected into the tunnel flow. This method has been documented in Reference 14. Because of this correction, considerable care was required in the accurate measurement of the injected mass flow, and a measurement technique was developed at the de Havilland Division using a calibrated perforated plate inside the model. This plate was also used to smooth out any internal flow disturbances before being injected into the ejector formed by the trailing shrouds. Model Reynolds numbers were mostly around $Re = 20 \times 10^6$ (i.e. typical flight values for a transport aircraft around 150,000 pounds, or 68,000 kg). Buffeting conditions were detected in these two-dimensional tests as a large increase in the fluctuating normal loads on the rear balance pin picking up the airfoil. Pressure measurements were taken around all three foil surfaces.

Three-dimensional reflection plane testing has been performed on two wing planforms in two different pressurized transonic wind tunnels. An unswept wing, Figure 10, incorporating the 18% thick foil WT-CC (of Figure 8) was tested in the NASA, Ames 11 foot x 11 foot transonic facility in California in the late '70s. A 20 degree swept wing (Figure 11) incorporating the 24% thick foil WT-CT of Figure 8 was tested in the mid-'80s in the NAE 5 foot x 5 foot tri-sonic blowdown facility in Ottawa.

Effective Drag ($C_{D_{EFF}}$)

To obtain a readily appreciated measure of the influence of blowing on any foil at forward speed, in particular with the augmentation of thrust experienced with ejector foils, it is our general practice to add the static (i.e. zero q) blowing thrust coefficient of the nozzle alone, C_{J_N}, i.e. without the shrouds or flaps, to the wake rake or balance "drag-minus-thrust" measurements for the configuration (Figure 12). This effectively treats any thrust augmentation (low speed) or boundary layer re-energization (high speed) as an effective reduction in profile drag. Effective drag coefficient, $C_{D_{EFF}}$ can be compared directly, therefore, with the profile drag coefficient of conventional unblown wings or foil sections. Note that for "externally blown" flaps, where jet thrust impinging on the flaps is degraded due to scrubbing friction along the wing surfaces, this technique would reflect an increase in effective drag due to a thrust efficiency less than unity. This highlights one potential of the augmentor-wing concept where the augmentation of thrust overwhelms any scrubbing friction losses.

Two-Dimensional Characteristics

Unblown Data

The variation of the unblown, profile drag (C_{D_W}) with thickness/chord of the two multi-foil sections designed for $C_{L_D} = 0.6$, at t/c = 18% and 24%, are shown in Figure 13 against several other transonic foils of conventional design, tested in the same wind tunnel using the same measuring techniques. Two empirical curves for conventional sections at $C_{L_D} = 0$ and 0.6, using the method by Hoerner (Reference 15), are shown also to indicate the trends with thickness/chord. Two facts are immediately evident from this data. Firstly, the 18% thick multi-foil section has a significant increase in profile drag relative to conventional sections, due to the increased skin friction of the additional internal surfaces of the shroud foils. However, equally evident is the control of form drag with the multi-foil sections, which indicate that, at $t/c \approx 25\%$, those sections exhibit about the same profile drag (form plus friction) as a conventional foil. In fact, the slope of the curve for the multi-foil sections is more closely represented by that of the $C_{L_D} = 0$ empirical curve, where the boundary layers will be much thinner. At thickness/chords greater than 25%, it is expected that the multi-foil sections will have even lower profile drag than conventional foils.

An interesting set of data for foil NAE 68-060-21.1, jointly developed by NAE and the de Havilland Division, is also shown on Figure 13. This foil, at 21% thickness/chord, exhibited significant runs of natural laminar flow, even at high Reynolds numbers (Reference 16), which accounts for its low drag level in relation to the rest of the empirical data which has boundary layer transition at, or very near, the leading edge. The particular significance of this foil that is highlighted here is that, with its relatively thin boundary layers, its drag rise Mach number approaches within $\Delta M_D = 0.01$ of that of the multi-foil section characteristics (Figure 14). The drag rise characteristics for the multi-foil sections show higher drag rise Mach numbers than conventional foils at the same thickness/chord, but only marginally so for this NLF foil. The high drag rise Mach numbers achieved with the multi-foil concept are also felt to be a reflection of the control of form drag.

An alternative way of presenting drag creep and drag rise data is shown in Figure 15, where the profile drag increment, above the drag at low Mach number, is plotted. All the foils exhibit the same general drag creep characteristics, but the multi-foil sections are relatively better with regard to drag rise.

The control of form drag with angle of attack for the unblown sections can also be seen, typically (from Figure 16a), for the 24% thickness/chord foil, where unblown there is only 4 cts drag variation between the C_L at minimum drag, say $C_L = 0.6$, and $C_L = 0.89$. Whereas, at least 10 cts would have been expected for a conventional foil of the same thickness/chord, with the maximum thickness well aft and with turbulent boundary layers starting from near the leading edge. Similarly (from Figure 16b) for the 18% thick foil, WT-CD, we can see 10 cts of drag increase from minimum drag over a lift increment of $\Delta C_L = 0.54$. In this case, a 30 cts increase would not be unreasonable for a similar thickness conventional foil.

Blown Characteristics

The effect of blowing between the shrouds on the effective profile drag $C_{D_{EFF}}$ can be seen typically in Figures 17, 18 and 19 for three of the foils tested. The effective drag can be seen to reduce significantly with cruise blowing coefficients, giving $\Delta C_{D_{EFF}} / C_{J_N}$ between -0.02 to -0.07 ($\phi = 1.02$ to 1.07). These figures show that, in the mid-Mach number range, the drag reduction due to blowing can more than offset the increased skin friction of the multi-foil geometry.

For the very thick wing, $t/c = 24\%$, blowing can be seen to be a disadvantage at the higher Mach numbers (Figure 20). At low Mach numbers, thrust augmentation overwhelms whatever characteristic creates the initial "profile" drag increase at low C_{J_N} (in Figure 20). This drag increase is now considered to be due to the extreme curvature of the main foil section shape just ahead of the lower intake (Figure 8). The curvature here became progressively more severe as foil thickness was increased, due to the inadequate theoretical representation within the intakes at that time. This denied a flexibility to fully control the intake and overall diffuser area ratios between the intakes and exit of the ejector. The lower intake shape has been modified now, using the latest theoretical approach, (see Figure 37 and discussion: "Potential Developments" following), and it is expected that the new foil will show no drag increase with blowing at low C_{J_N}.

Figures 21 and 22 provide an alternative approach to showing the influence of blowing at constant NPR for two cases, Figure 21 for the thinner foil, WT-CC, showing drag reduction over the whole speed range, and Figure 22, for the 24% thick foil, showing the degradation described previously at higher Mach numbers.

Generally, blowing favourably influences the foil characteristics by delaying any incipient separations at high or low angles of attack. That is, in effect, linearizing the $C_L \sim C_{D_{EFF}}$ curves even more (see Figure 23 for an 18% thick foil). An even more dramatic clean up can be seen for the 24% thick foil (Figure 24), which, because of the sharp curvature into the lower intake (previously described), experienced a severe boundary layer separation at lift coefficients below $C_L \approx 0.4$. Even a relatively small amount of blowing, well below cruise values, cleaned up this separation. This severe lower intake separation for the thicker foil will be eliminated with the revised foil shape (Figure 37).

Since the shrouds lie in a sensibly invariant flow field, directly behind the main foil, and are thus insensitive to angle of attack changes, any foil buffeting at high speed is due to flow separations on the main foil. These main foil separations, in turn, are reduced or eliminated by the presence of the shroud foils delaying foil buffeting. With its effect on boundary layer separation, it would be anticipated that blowing would delay foil buffeting even more. Figure 25 (from Reference 17) shows some typical buffet measurements observed from the RMS of the normal load data taken from the rear support pin of the 2-D balance. This provides a convenient measure for the strength of separation. Generally, buffet onset coincided with the main break in the lift curve, which is well beyond the design lift coefficient for the section. At the higher Mach numbers, buffeting was due to shock induced separation on the main foil upper surface. The data of Figure 25 show that, relative to the level achieved with the unblown foil, the buffet levels with blowing are reduced. It is also felt that the unblown multi-foil will have a buffet level below that of the single conventional airfoil because of the containment of the main foil boundary layers by the shroud foils when separated. But this has yet to be quantified.

Figure 26 shows the approximate maximum or buffet onset lift coefficients for the 24% thick airfoil at zero flap angle, both unblown and blown. The power of blowing at the lower Mach numbers due to boundary layer control, and also to jet flap supercirculation, can be seen. In most cases $C_{L_{max}}$ (NPR = 3.0) was never reached during an α sweep, and the $C_{L_{max}}$ curve presented in Figure 26 is felt to be conservative. Figure 27 shows at NPR = 1.0, the unblown multi-foil section contains the separated flow on the upper surface within the intakes; see lift break at about C_L = 1.2. The same figure shows also that only a small amount of blowing, C_{J_N} = 0.11 at M = 0.15 (equivalent to T/W ≈ 0.02 DGW, or approximately 6% of the installed thrust for cruise), provides significant control of the upper surface boundary layer.

The influence of a moderate flap angle, δ_f = 10 degrees at low speed, is presented in Figures 28 through 30. Figure 28 shows the effect on lift curve slope. Figure 29 displays the powerful influence of the ejector augmentation at low speed for this configuration, even though the ejector diffuser area ratio was not optimized for low speed flight. An average thrust augmentation of ϕ = 1.2 ($\Delta C_{D_{BFP}} / C_{J_N}$ = -0.2) can be seen for this configuration. With $C_{D_{BFP}}$ = -0.15, not only would the total profile drag of an aircraft be effectively eliminated by this effective reduction in drag, but a significant proportion of any induced or vortex drag would also be effectively offset. This highlights, very simply, the thrust efficiency of the augmentor-wing high lift system relative to externally blown concepts, which require nearly twice the installed thrust of the ejector concept for the same airfield performance. In fact, with an optimized augmentor flap, the augmentor-wing aircraft can achieve its short field performance with only the thrust installed for cruise and with one engine out.

Figure 30 presents the data as $C_L \sim C_{D_{BFP}}$, showing how a small amount of blowing maintains attached flow initially, and then heavier blowing augments the thrust due to the ejector action and the lift due to jet flap supercirculation.

Three-Dimensional (Reflection Plane) Characteristics

As mentioned previously, two reflection plane tests have been performed during the course of the multi-foil wing development to-date. The first was with an unswept wing model (Figure 10), incorporating a full span, 18% thickness/chord foil section, WT-CC, at a design lift coefficient C_L = 0.35. This test was carried out in the 11 foot x 11 foot transonic pressurized wind tunnel at NASA, Ames in California. This test had two principal goals. First, it was to confirm that the method of wake rake profile drag measurement for the 2-D sections was valid. In particular, for the blown configurations, where a significant correction must be applied to the measured rake data to account for the mass momentum introduced into the tunnel by the blowing flow. Secondly, it was to confirm the control of form drag with angle of attack in the 3-D environment. The second study was on a 20 degree swept and twisted wing with a full span 24% thick WT-CT foil at a design lift coefficient C_L = 0.6 (Figure 11). This test was performed at the NAE tri-sonic pressurized 5 foot x 5 foot blowdown wind tunnel in Ottawa. This swept wing test had the same goals as the first test for a thicker, higher lift foil, but with the additional goal of determining the effects of sweep on the multi-foil characteristics.

Figure 31 documents the results from the straight wing test in comparison with its 2-D section characteristics. When suitable corrections have been made to bring the two tests into line, a remarkably good correlation is observed. Some of the discrepancy in the unblown data arose due to a small separation observed in the lower intake, particularly towards the wing tip. Measurement of the foil locations after the test showed a geometrical discrepancy in the lower shroud outboard. This separation was eliminated with blowing, and the figure shows that the correlation between 2-D and 3-D, with blowing, was good.

Figure 32, again for the straight wing test, demonstrates very clearly the remarkable control of form drag exhibited by the multi-foil section, both unblown and blown. In this figure, the nozzle thrust, C_{J_N}, and the vortex drag $(C_L^2 / \pi A)$, for the unblown configuration, C_{J_N} = 0, or $C_L^2 / (\pi A + 2 C_{J_N})$ for the blown configuration, has been removed from the measured data from the balance to leave the foil profile drag or effective profile drag, respectively. The virtually invariant profile drags over a lift coefficient range from C_L = -0.3 to +0.7 in the mid-Mach number range M = 0.6 to 0.7, are evidence of the remarkable control of form drag with the section. At the lower Mach numbers, the reduction in drag at higher positive and negative lift coefficients, i.e. indicating <u>apparent</u> induced drag factors, k (= $\pi A \, C_{D_i} / C_L^2$) less than unity, are due to the need for tunnel corrections. At lower Mach numbers, the low porosity (6%) of the tunnel walls is such that the tunnel behaves more closely like a closed section, and thus corrections would add to the drag at high positive and negative lift, straightening the curves. At the higher Mach numbers, no tunnel corrections are required. Comparison between the blown and unblown characteristics in Figure 32 also show the reduction in effective profile drag due to blowing.

Results from the swept wing studies of the second reflection plane test for the <u>unblown</u> section were clouded when it was found that the section was separated in its upper intake. It became evident from the test data that, for the flow into the intakes, the locations of the shrouds and the intake diffuser area ratios should be determined more from a streamwise section than, say, a section normal to the quarter-chord. Increasing the ejector diffuser area ratio of the configuration improved the unblown characteristics slightly, but the main foil upper surface was still separated. The model had insufficient adjustment capability in the flap bracket mounting system to move the foils sufficiently close to the main foil. As Figure 33 shows, however, separations were cleaned up with blowing on the foil, and a fairly reasonable correlation was achieved with the blown 2-D data for Mach numbers up to M = 0.6. Above M = 0.6, the drag creep for the 3-D section appears to be somewhat "smeared" relative to the 2-D data, due to 3-D effects, no doubt, but the eventual drag rise, M_D ≈ 0.75, appears to correlate well with the 2-D data when corrected for sweep. Figure 34 shows much the same degree of correlation between the 2-D and 3-D lift data, with a good correlation for Mach numbers less than M = 0.62, and then a gradual approach of the 3-D lift data towards the sweep-corrected 2-D data at M ≈ 0.73 and above. A 3-D design point of C_{L_D} = 0.6 at M = 0.7 has been achieved with the 20 degree swept wing.

Figure 35 shows, typically, that the $C_{D_{BFP}} \sim C_L^2$ curves, with blowing on, were very linear over a wide range of lift coefficients. Figure 36 presents the results over the Mach number range tested, and shows an induced drag factor of unity between M = 0.3 and 0.7. Again, these factors highlight the control of profile drag with the multi-foil section. It should be noted that tunnel corrections were applied to this swept wing data using the method of Mokry (Reference 19). This method matches tunnel wall pressures measured along rails on the tunnel walls. These corrections reduced the measured drag of the model, more appropriate to an open tunnel, due to the 20% porosity of the tunnel walls.

POTENTIAL DEVELOPMENTS

The theoretical approach has been improved, as mentioned previously, whereby we have more confidence in predicting the characteristics of the flow within the intakes to the shrouds, and thus have better control in predicting the foil geometry. We have modified the basic 24% thick, C_{L_D} = 0.6 foil coordinates therefore, in the vicinity of the lower intake (Figure 37), with a view to delaying the separation of the boundary layer into the lower intake, unblown, to much lower lift coefficients. We also expect a 5 to 10 count reduction in unblown profile drag at higher lift coefficients with this change. The change in the lower intake shape will also allow the collective diffuser area ratios of the upper intake, the lower intake and the overall ejector of the thicker foil to be set more optimally. We expect to achieve a drag reduction with blowing at high Mach numbers, as experienced with the other multi-foil sections. It should be noted that the foil still retains the capability for a simple hinge point for the flap system, to allow flap deflections up to δ_f = 60 degrees, and achieve Coanda attached flow around the lower shroud upper surface when blown.

The theoretical method was also used to develop a family of foils of varying flap/chord ratio, C_f/c = 35%, 30% and 25% for thickness/chords of 18%, 24% and 30% (see Figure 38 for a typical selection). Using incremental drags from this study, the influence of lower skin friction drag due to shorter flap/chord ratio can be seen in Figure 39. The cross-over point with conventional foils is seen to reduce from approximately 24.5% thickness at C_f/c = 35% to 22.5% thickness with a flap/chord ratio of C_f/c = 0.25.

APPLICATIONS FOR THE VERY THICK MULTI-FOIL WING

There are several potential aircraft applications where a very thick, high aspect ratio, high speed multi-foil wing, could prove of significant value. Most of these applications would be with the wings blown to take advantage of the very high lift and low effective drag capability of the multi-foil configuration at low speed, but unblown applications are considered possible also.

As noted previously, the initial impetus for the development of the thick multi-foil wing section was the desire to simplify the ducting system in a blown wing for a high speed Advanced USTOL Tactical Transport Aircraft. As a next step to the low speed Augmentor-Wing Research Aircraft USTOL demonstration program described earlier, a high speed USTOL demonstrator aircraft has been marketed by Boeing Canada, de Havilland Division and the Canadian Government for several years as a potential operational demonstrator program. This proposal is based upon the use of a basic C-130 Hercules fuselage and empennage with a completely new wing incorporating the 24% thick, high speed multi-foil wing (Figure 40). The aircraft would be powered by two proposed Pratt and Whitney blowing engines (Figure 41), based upon the PW2037 engine used in the Boeing 757 and McDonnell-Douglas C-17 aircraft. According to Pratt and Whitney, this blowing derivative engine would have 80% commonality with the basic PW2037. A description of this aircraft, powerplant, and its performance capabilities can be found in Reference 1. Suffice it to say that this aircraft would achieve its USTOL performance into field lengths less than 1500 feet, to or from a 50 foot barrier, with only the thrust required for cruise, i.e. $T/W \approx 0.3$. The blowing system requires only 40% of the installed thrust and can be contained in a single cross-over duct system aft of the rear spar in this very thick wing. Duct flow cross-over at the fuselage permits the economy of a twin engine layout to be exploited.

A proposal to extend the multi-foil concept to STOVL capability was offered to the U.S. Navy for a medium speed carrierborne transport aircraft (Figure 42). Vertical landing capability would be achieved with partial tilt of the wings by 30 degrees, and partial thrust deflection from the primary thrust nozzles of θ_N = 60 degrees. The powerplant proposed for this concept was a Rolls-Royce Pegasus engine, with the fan thrust, blowing the wings, approximately 50% of the total thrust.

The ability to design the multi-foil to very thick sections and very high design lift coefficients, say C_L = 1.0, would be ideal for high altitude long endurance reconnaissance aircraft, such as shown in Figure 43.

The very thick multi-foil section would also give sufficient wing depth to permit span-loader concepts starting at design gross weights as low as 300,000 pounds (136,000 kg) (Figure 44).

CONCLUSIONS

With the powerful control of form drag exhibited by the multi-foil section described in this note, a potential has been shown for very thick, high speed multi-foil sections to have unblown profile drags the same as, or less than, that of conventional foils, at the same design lift coefficient, for thickness/chords greater than 22 to 25%.

The control of form drag with the multi-foil section also embraces α, or lift-dependent variations, and these have been shown to reduce to that of the vortex drag contribution alone. That is, $k\ (=\pi A\ \partial C_D / \partial C_L^2) \approx 1.0$, possibly 25% less than with conventional foils. The control of form drag has been shown also to yield higher drag rise Mach numbers for the multi-foil section than for conventional supercritical foils of the same thickness/chord.

Combination of blowing with the multi-foil section has been shown to considerably reduce the effective profile drag of the section at low speed due to thrust augmentation in the ejector passage between the trailing foils. In fact, at very low speed, M < 0.15, typical of takeoff and landing speeds, the thrust augmentation is sufficiently high to effectively offset all of the profile drag and a significant proportion of the induced drag of any aircraft configuration. In the middle Mach number range, M = O.3 to O.5, the reduction in effective drag of the multi-foil section due to blowing is more than sufficient to offset any skin friction penalty the three-foil configuration incurs. At higher speed also, thrust augmentation (or possibly boundary layer re-energization) has also been demonstrated, to the amount of ϕ =1.05 to 1.02, which will reduce the effective profile drag of the multi-foil section. Attention to the high speed multi-foil geometry should allow this blowing thrust "augmentation" at high speed to be optimized for all foil sections.

Several potential applications have been suggested where the very thick, high speed multi-foil sections may have a distinct advantage over more conventional foils.

Future experimental work should possibly focus around the improvements to the 24% thick foil and its application to the swept wing reflection plane model. On the theoretical side, a code begun many years ago to simulate the blown ejector characteristics should be completed, now that the intake flows are better calculated.

REFERENCES

1. Farbridge, J.E., "A Review of the de Havilland Augmentor-Wing Powered Lift Concept and Its Future Applications." SAE Paper No.872313 (presented at the International Powered Lift Conference and Exposition), Santa Clara, California, December 7-10, 1987.

2. Garland, D.B., "Development of Lift Ejectors for STOVL Combat Aircraft." SAE Paper No.872324 (presented at the International Powered Lift Conference and Exposition), Santa Clara, California, December 7-10, 1987.

3. Farbridge, J.E. and Smith, R.C., "The Transonic Multi-Foil Augmentor-Wing." AIAA Paper No.77-606 (presented at the AIAA/NASA, Ames V/STOL Conference), Palo Alto, California, June 6-8, 1977.

4. Wilby, P.J., "The Calculation of Subcritical Pressure Distributions on Symmetrical Aerofoils at Zero Incidence." NPL Aero Report 1208, 1967.

5. Labrujere, T.E., Loeve, W. and Slooff, J.W., "An Approximate Method for the Calculation of the Pressure Distribution on Wing-Body Combinations at Subcritical Speeds." AGARD CP No.71, Paper 11.

6. Sasman, P.K. and Cresci, R.J., "Compressible Turbulent Boundary Layer with Pressure Gradient and Heat Transfer." AIAA Journal, Vol.4, No.1, January 1966, (pg.19-25).

7. Harris, A., "A Compressible Theory for Augmentor Multi-Foil Sections." DHC-DITC 84-4, September 1984.

8. Lieblin, S. and Stockman, N.O., "Compressibility Corrections for Internal Flow Solutions." Journal of Aircraft, Vol.9, No.4, April 1972, (pg.183).

9. Dietrich, D.A., Oehler, S.L. and Stockman, N.O., "Compressible Flow Analysis About Three-Dimensional Wing Surfaces Using a Combination Technique." AIAA Paper No.83-0183, January 1983.

10. Harris, A., "A Review of the Technical Data Base for the Cruise Augmentor Transonic Airfoil." DHC-DND 85-2, October 1985.

11. Harris, A., "Compressibility Corrections for Multi-Foil Sections." Journal of Aircraft, Engineering Notes, Vol.23, No.2, February 1986.

12. Flores, J., Holst, T.L. and Sorenson, R.L., "Transonic Solutions for a Multi-Element Airfoil Using the Full Potential Equations." AIAA Paper No.84-0300, January 1984.

13. T. A. Lasinski, T.A. and Andrews, A.E., "Computation of the Steady Viscous Flow Over a Tri-Element Augmentor-Wing Airfoil." AIAA Paper No.82-0021, 1982.

14. Peake, D.J. and Bowker, A.J., "A Simple Streamwise Momentum Analysis to Indicate an Empirical Correction to Angle of Incidence in Two-Dimensional Transonic Flow due to a Perforated Floor and Ceiling of the Wind Tunnel." NAE LTR-HA-11.

15. Hoerner, "Fluid Dynamic Drag."

16. Eggleston, B., "Thick Supercritical Airfoils with Low Drag and NLF Capability." ICAS Paper No.86-1.1.1 (presented at the 15th Congress of the International Council of the Aeronautical Sciences), London, England, September 1986, (Fig.10).

17. Harris, J.L., "Analysis of Results from Tests of an 18% Thick High Speed Augmentor-Wing Model (WT-CC) in the NAE Two-Dimensional High Reynolds Number Blowdown Tunnel." DHC-DND 77-1, March 1977.

18. Khalid, M. and Jones, D.J., "Experimental Investigation of a 21% Thick Supercritical Airfoil NAE 68-060-21.1 in the 15" x 60" Facility." NAE LTR-HA-5 x 5/0155, March 1985.

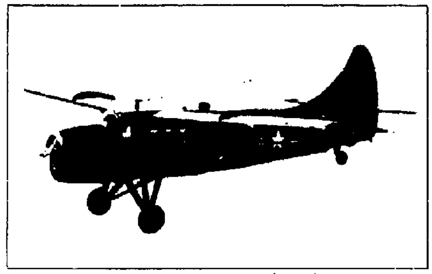
19. Mokry, M., Digney, J.R., and Poole, R.J.D., "Double-Panel Method for Half-Model Wind Tunnel Corrections." Journal of Aircraft, Vol.24, No.5, May 1987, (pg.322-327).

ACKNOWLEDGEMENTS

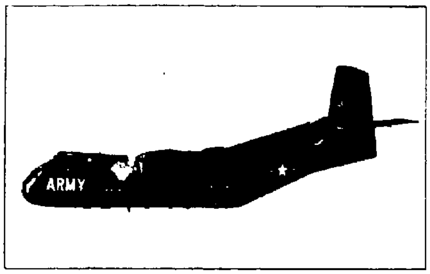
The research work on this multi-foil concept was supported largely by the Canadian Departments of National Defence and Industry Science and Technology.

Conventional STOL Canadian Airplanes Used by the U.S. Army and U.S. Air Force

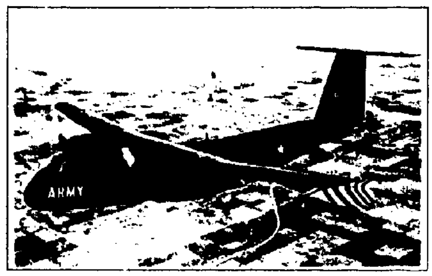
DHC-2 Beaver (L-20)



DHC-3 Otter (U-1)



DHC-4 Caribou (CV-2 & C-7)



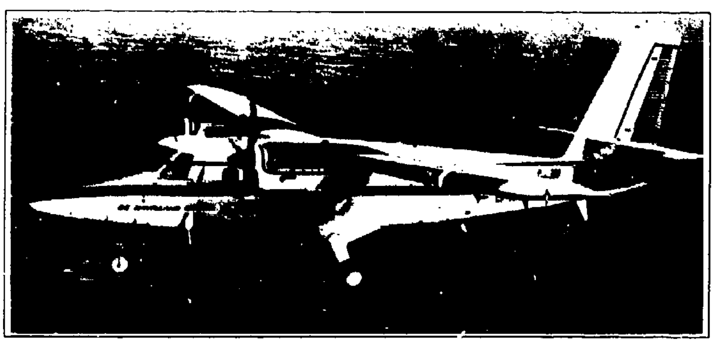
DHC-5 Buffalo (CV-7)

FAR0501A

Figure 1

de Havilland STOL Commuter Aircraft

DHC-6 Twin Otter



Dash 7

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Figure 2

Augmentor-Wing Research Aircraft

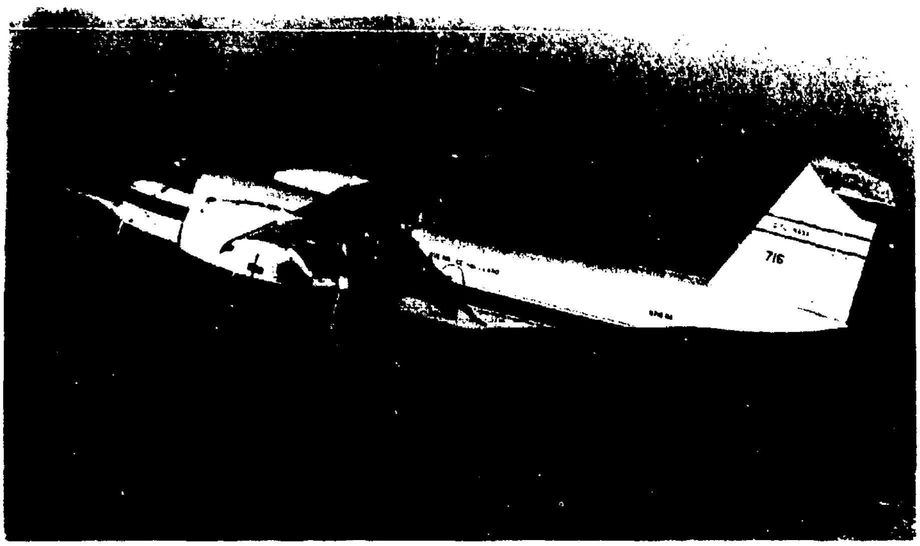

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Figure 3

E-7A Ejector Lift / Vectored Thrust STOVL Model
in NASA, Ames Wind Tunnel

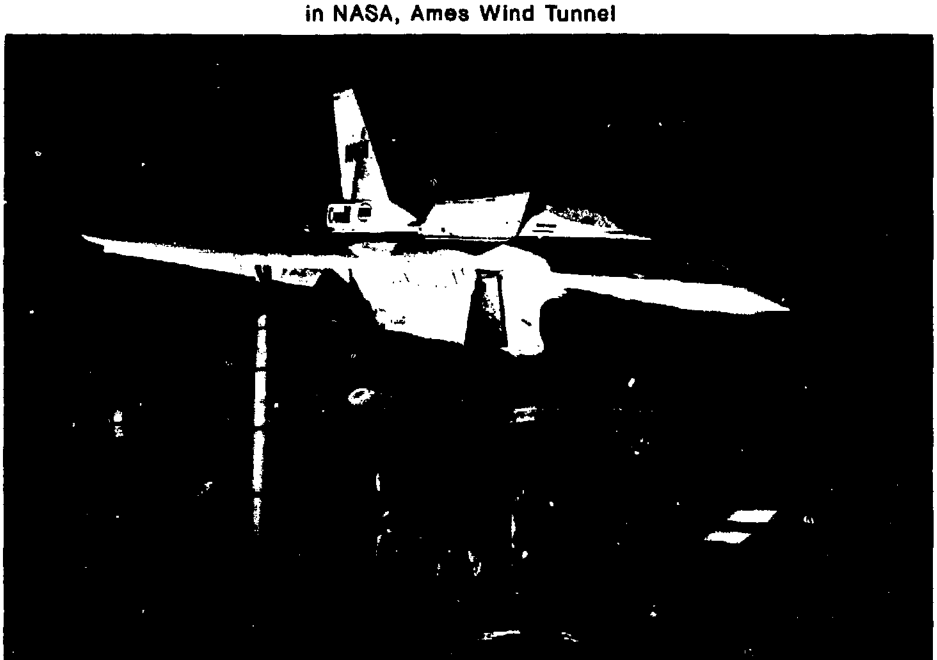


Figure 4

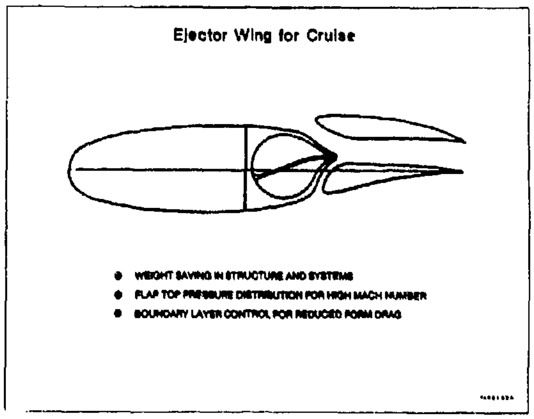


Figure 5

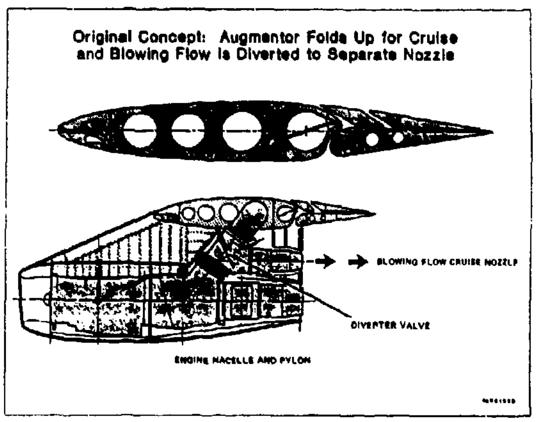


Figure 6

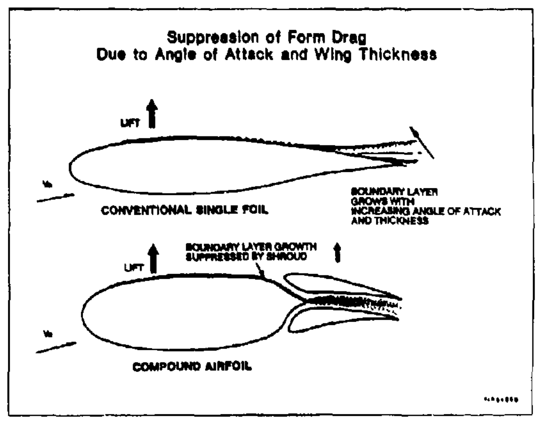


Figure 7

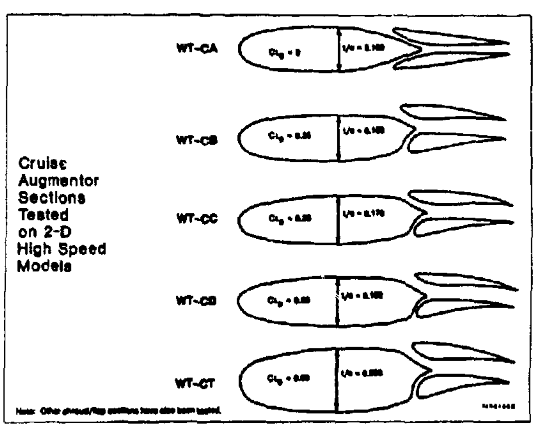


Figure 8

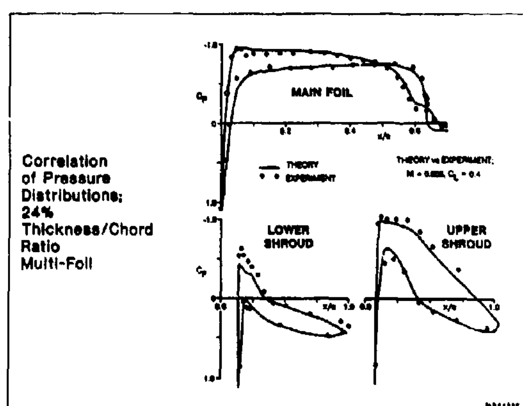
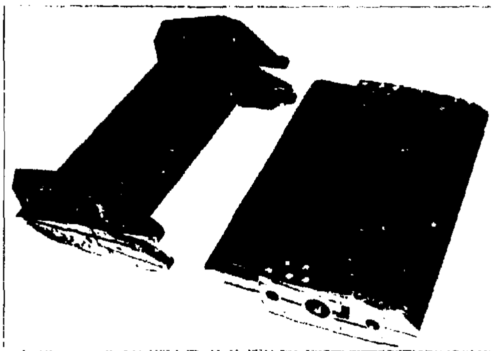
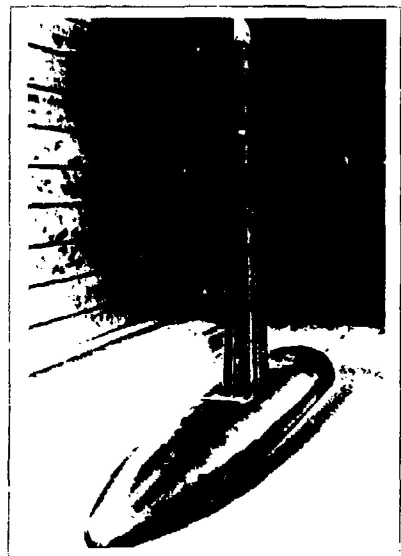


Figure 9

High Reynolds Number Model Tests - Compound Airfoil



2-D Model
in 5 x 5 ft NAE Wind Tunnel, Ottawa
(Re = 20×10^6)

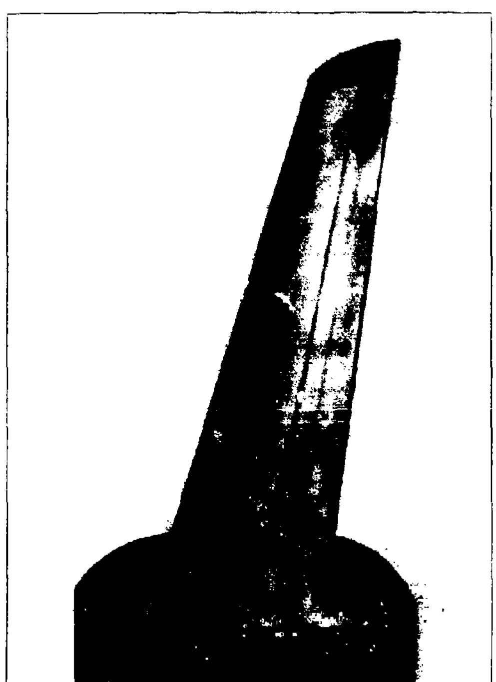


3-D Model
in 11 x 11 ft NASA, Ames Wind Tunnel
(Re = 10×10^6)

Figure 10

Reflection Plane
Compound Wing
Model

- 24% t/c
- 20 degree Sweep



FAR05028

Figure 11

Effective Drag, $C_{D_{EFF}}$, and Thrust Augmentation, ϕ

$$\boxed{C_{D_{EFF}} = C_{D_{wc}} + C_{J_N}}$$

WHERE $C_{D_{wc}}$ IS THE WAKE RAKE MEASUREMENT CORRECTED FOR THE BLOWING MASS FLOW.

$$\boxed{C_{D_{wc}} = C_{D_0} - \phi C_{J_N}}$$

WHERE: C_{D_0} IS THE UNBLOWN PROFILE DRAG COEFFICIENT OF THE CONFIGURATION;

C_{J_N} IS THE MEASURED STATIC NOZZLE THRUST.

AND ϕ IS THE THRUST AUGMENTATION RATIO OR EQUIVALENT BOUNDARY LAYER RE-ENERGIZING.

THUS, ϕ CAN BE RECAST AS:

$$\phi = \frac{C_{J_N} + C_{D_0} - C_{D_{EFF}}}{C_{J_N}} = 1 - \frac{\Delta C_{D_{EFF_{C_J}}}}{C_{J_N}}$$

AND $\Delta C_{D_{EFF_{C_J}}} = C_{D_{EFF}} - C_{D_0} = C_{J_N}(1 - \phi)$

Figure 12

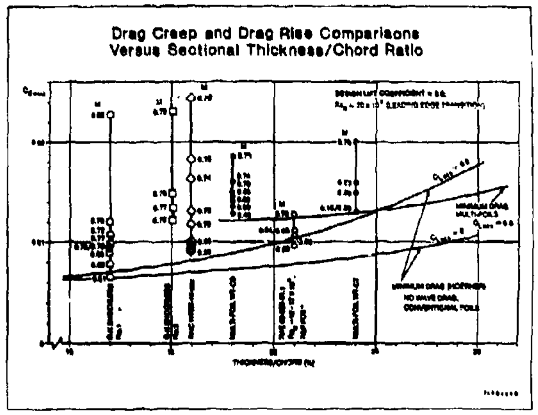


Figure 13

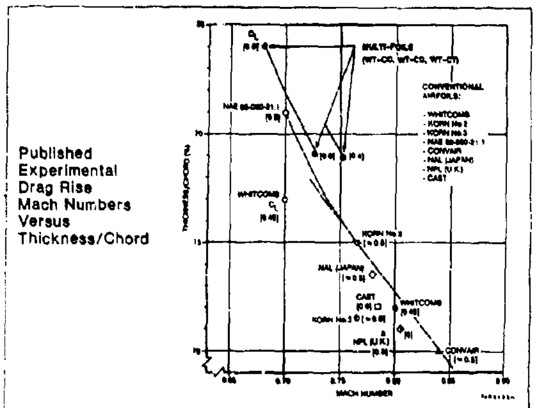


Figure 14

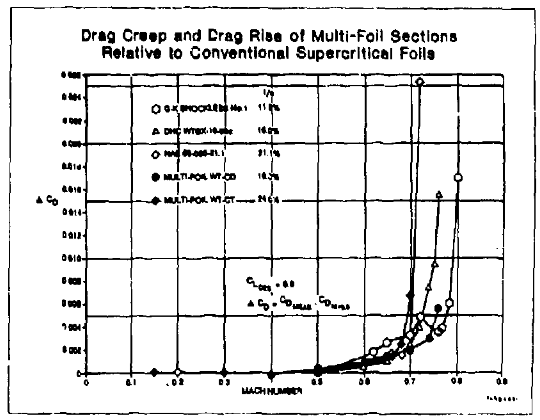


Figure 15

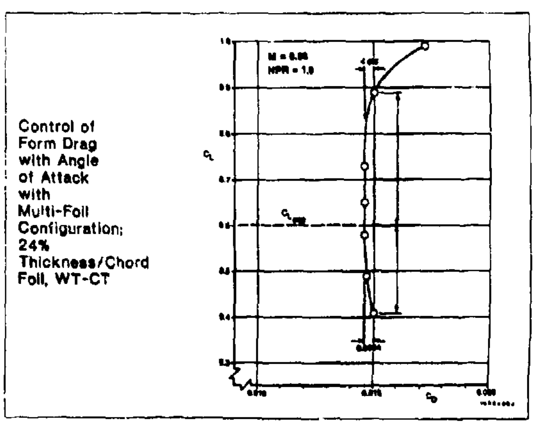


Figure 16a

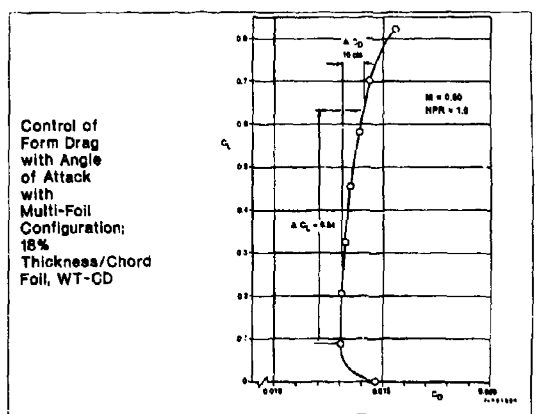


Figure 16b

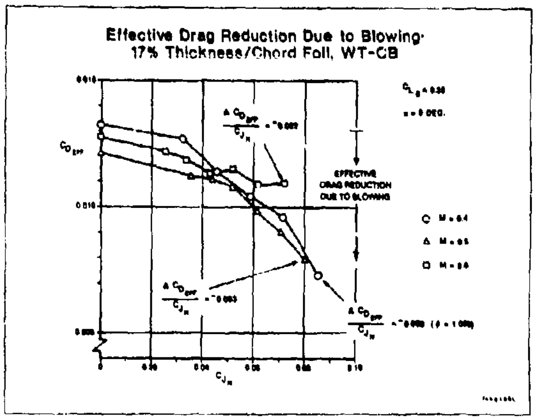


Figure 17

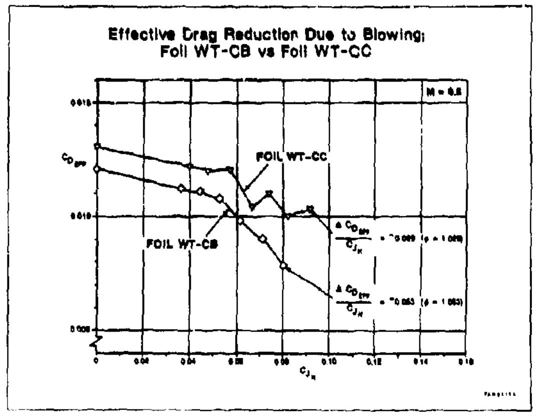


Figure 18

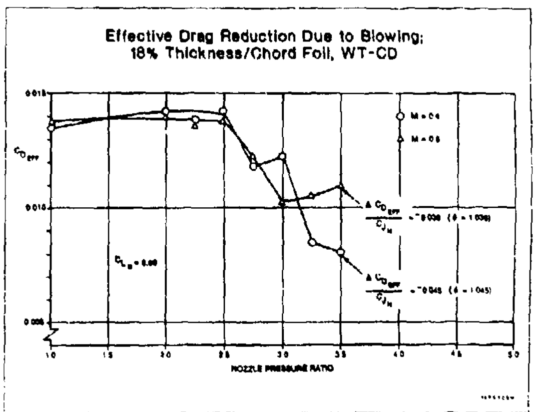


Figure 19

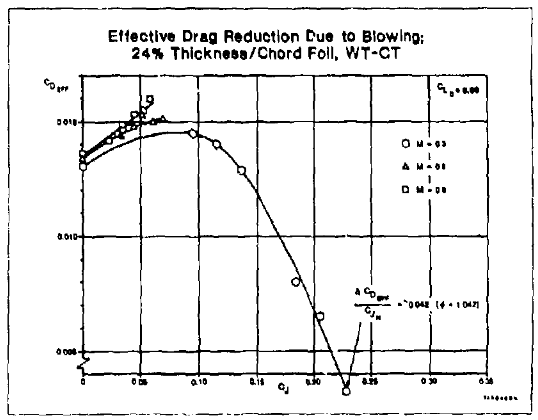


Figure 20

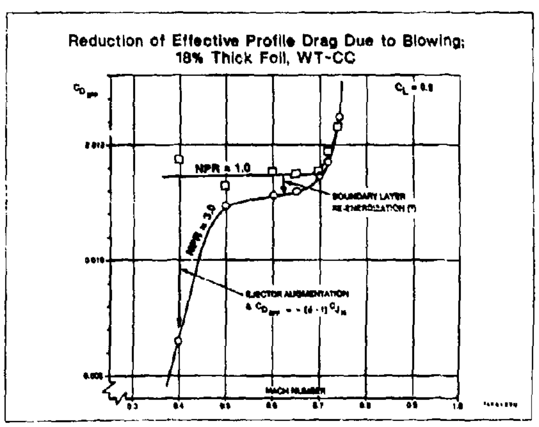


Figure 21

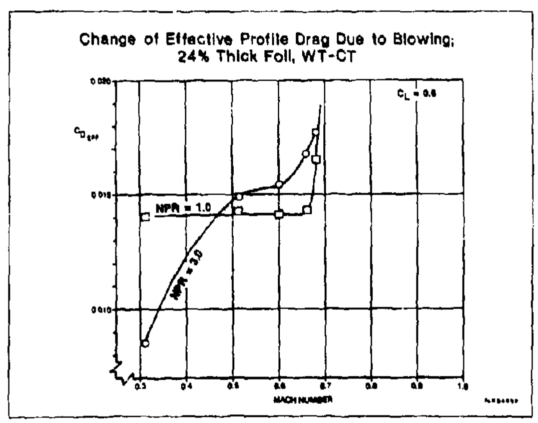


Figure 22

Control of Incipient Flow Separation with Blowing; 18% Thick Foil, WT-CD

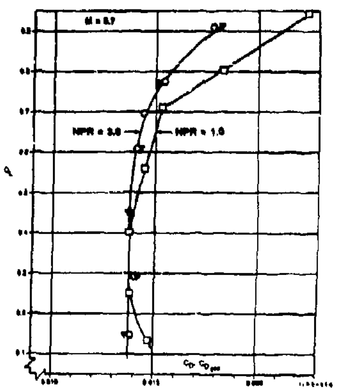


Figure 23

Elimination of Separation by Blowing; 24% Thick Foil, WT-CT

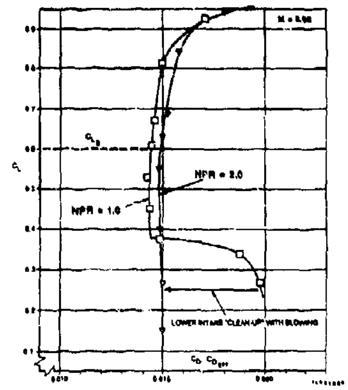


Figure 24

Effect of M and NPR on $C_{N_{max}}$ and $\Delta C_{N2_{rms}}$

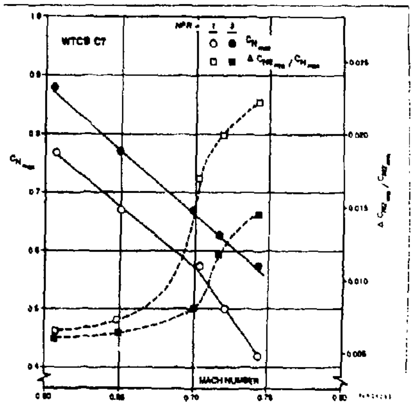


Figure 25

Maximum Lift Coefficients for 24% Thick Multi-Foil Section WT-CT

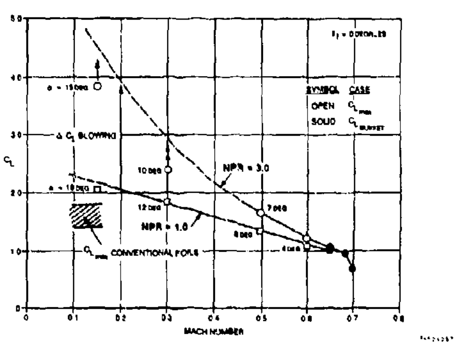


Figure 26

Effect of Blowing on Lift of 24% Thick Multi-Foil at Low Speed

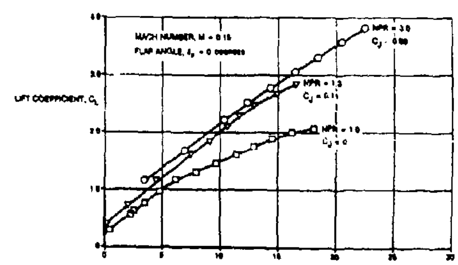
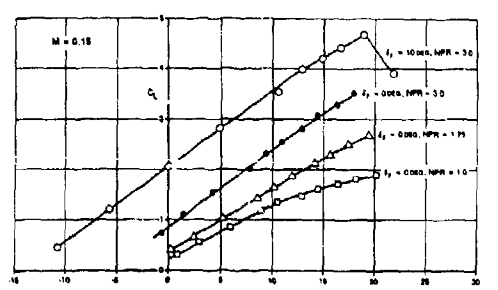


Figure 27

Influence of Flap Angle and Blowing on Lift Curve for 24% Thick Multi-Foil



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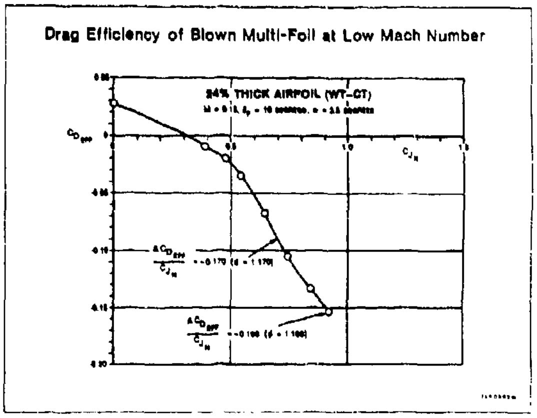

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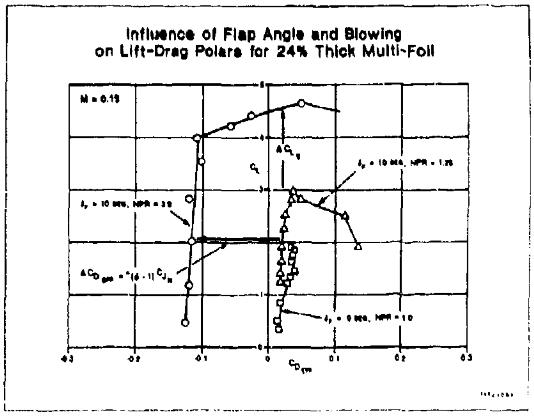
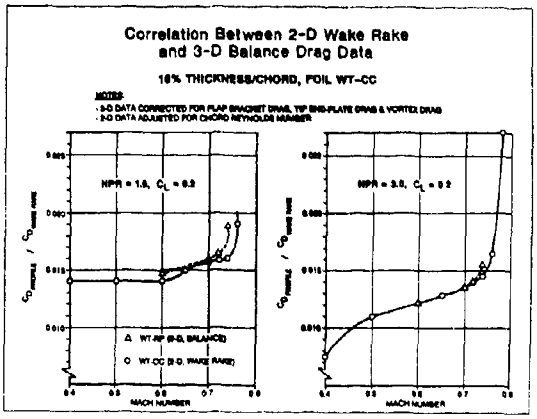


Figure 30



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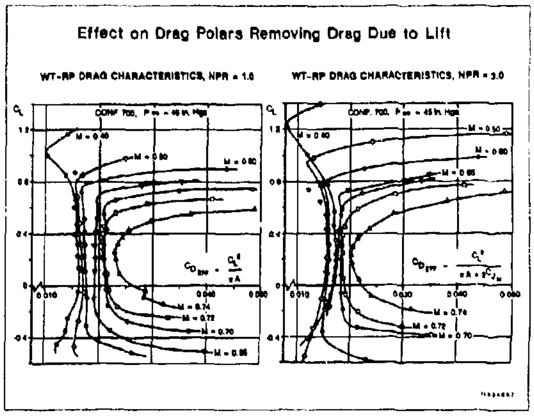

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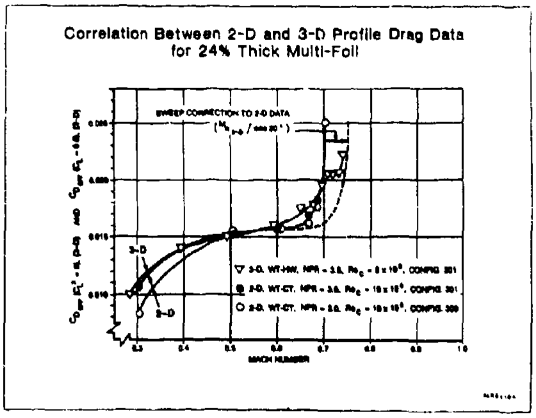


Figure 33

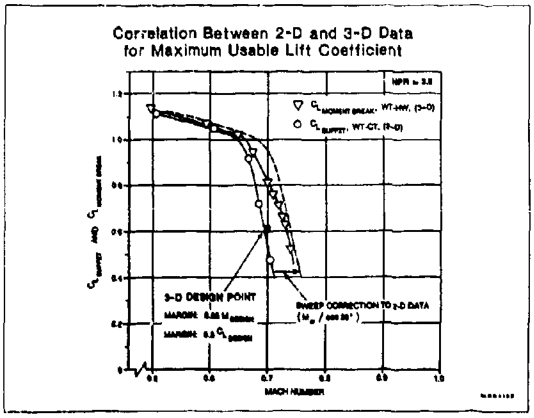
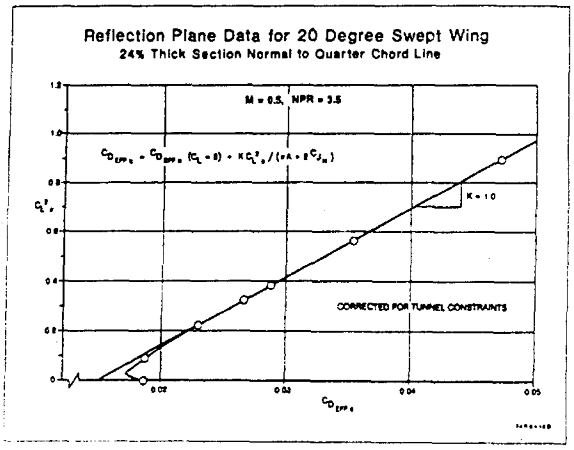


Figure 34



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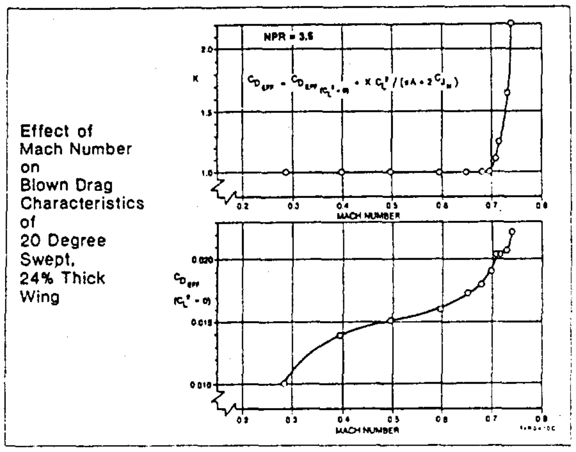
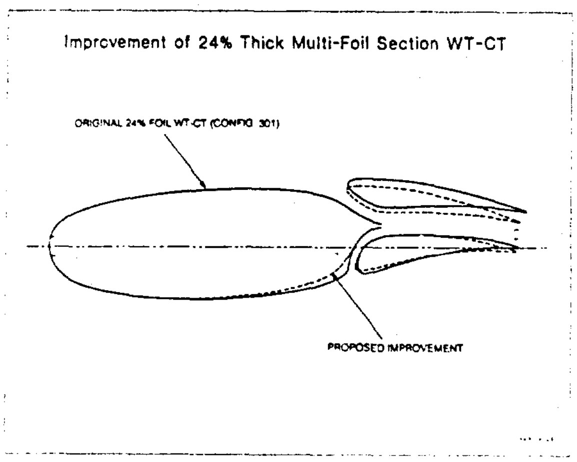


Figure 36



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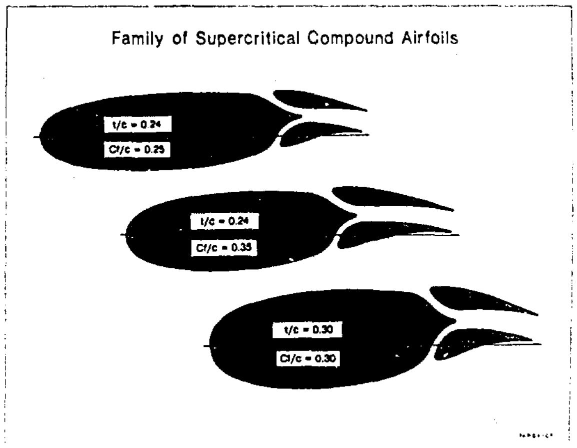

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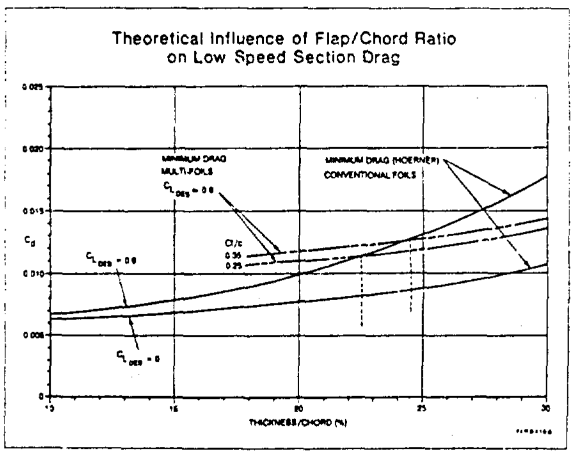

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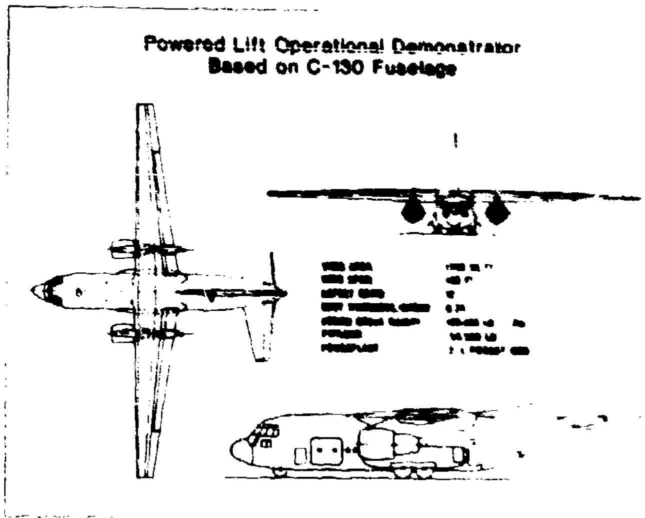

Figure 40

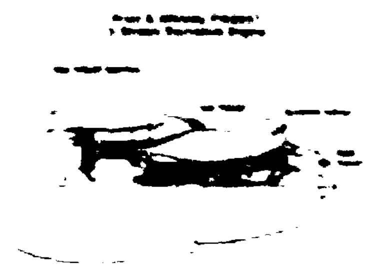

Figure 41

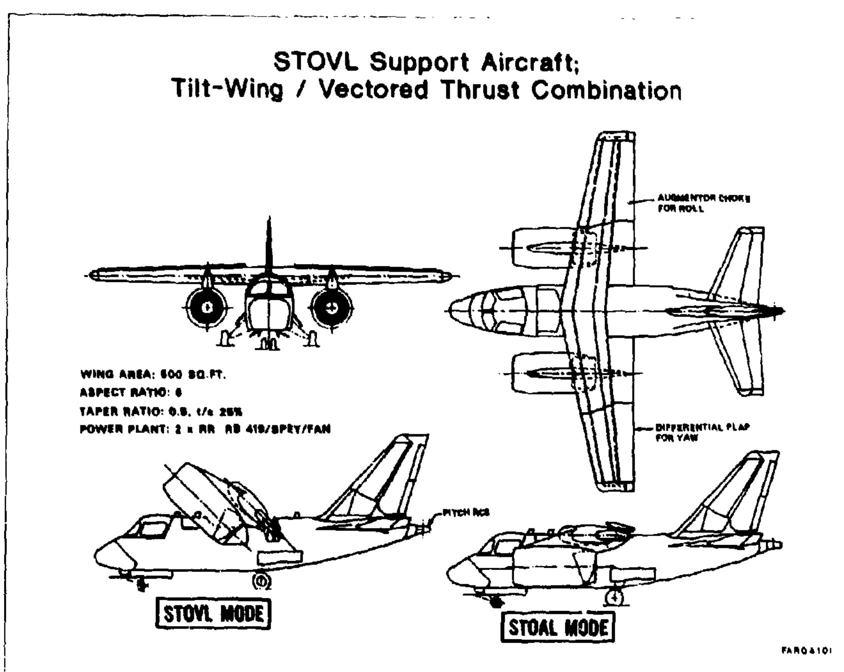

Figure 42

PS-05
High Altitude Long Endurance Aircraft (Compound Wing RPV)

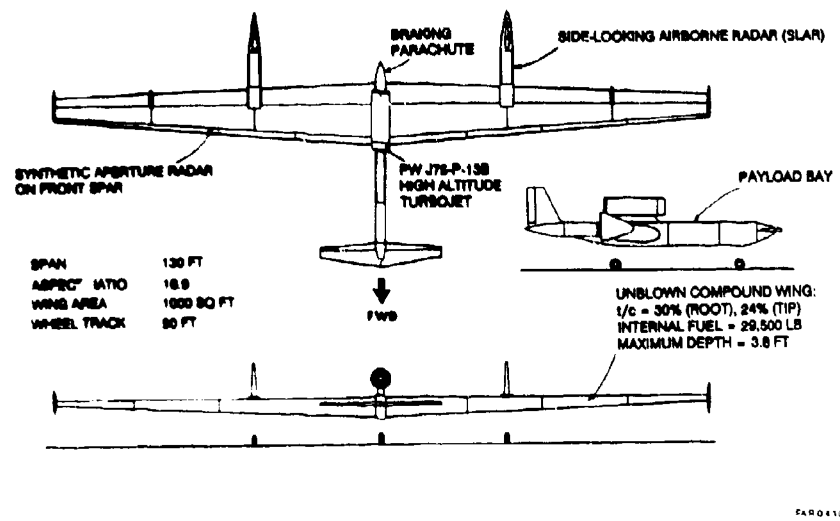

Figure 43

PS-03
Multi-Role Global Aircraft

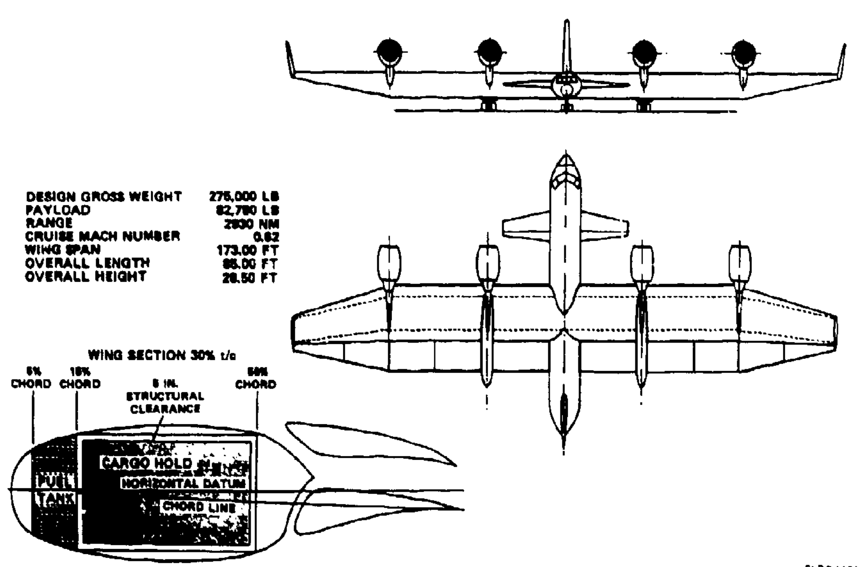

Figure 44

APPLICATION OF ADVANCED TECHNOLOGIES TO FUTURE MILITARY TRANSPORTS

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SUMMARY

This paper addresses long range military transport technologies with emphasis on defining the potential benefits of the hybrid laminar flow control (HLFC) concept currently being flight tested in a cost shared NASA, USAF, and Boeing program. Results of a 1990's global range transport study are presented showing the expected payoff from application of advanced technologies. The paper concludes with a technology forecast for military transports.

25 * Military aircraft, * Jet transport aircraft,

INTRODUCTION

The design of very long range aircraft and the important interrelationships of the primary design variables are illustrated in Fig. 1 which is based on the Brequet Range Equation. For a given specific fuel consumption and weight fraction, the lift to drag ratio (L/D) is the parameter to be optimized by the designer. This is accomplished by minimizing the fuselage drag, increasing wing aspect ratio to minimize induced drag, and by selection of high L/D airfoils.

Drag reduction by development of natural laminar flow (NLF) on aircraft wings has been a goal for over 50 years. Fig. 2 summarizes some of the test results beginning with the B-18 bomber flown in 1939, Reference 1. Modern transport wing half chord Reynolds numbers are shown at the applicable wing sweeps. It is clear that NLF alone will produce limited laminar flow benefits on these aircraft; therefore, some form of active laminar flow control is required to achieve significant drag reductions on large aircraft.

THE HLFC CONCEPT

The hybrid laminar flow control (HLFC) concept shown in Fig. 3 has active suction applied forward of the front spar of the wing. Natural laminar flow is maintained aft of the suction zone by appropriate airfoil selection and surface finish. Supercritical airfoils currently applied to aircraft like the Boeing 757 have compatible pressure distributions similar to that shown in Fig. 4. The other major factor which supports early application of the HLFC concept is the high quality manufacturing standards of todays aircraft industry. Current commercial aircraft are delivered with wing surface tolerances between the forward and aft spars which satisfy the criteria for a HLFC wing.

The HLFC concept shown in Fig. 3 provides for chemically anti-icing the wing and the same fluid would be applied to the wing through slots to prevent or remove insect contamination during takeoff and low altitude flight. (Insect contamination can cause boundary layer transition from laminar to turbulent flow.) Another concept for protecting the wing utilizes a Krueger high lift device which would shield the suction region from insect strikes and foreign object damage. In this concept, no lower surface laminar flow would be possible; however, improved wing high lift characteristics would be achieved.

GLOBAL RANGE TRANSPORT STUDY

The Global Range Transport Study reported in Reference 2 was sponsored by NASA-Langley Research Center and the Wright Research and Development Center (Formerly the Air Force Wright Aeronautical Laboratories). Lockheed Aeronautical Systems Co. performed this study which applied the HLFC concept to a military transport designed to carry a 132,500 lb (60,100 Kg) payload. The mission called for delivery of the payload 6500 nm and return empty and unrefueled. For this long range mission, fuel reserves include 5 percent of cruise fuel plus one half hour. A cruise Mach of .77 was specified and initial cruise altitude was fallout.

All of the airplanes were designed with technologies that will be available in 1994 and incorporated the following advanced flight control features:

- Four channel digital fly-by-wire
- Relaxed static stability
- Stability augmentation
- Maneuver load control
- Gust load alleviation
- Flutter mode control

The major improvements offered by the above features are: minimization of airframe weight, incorporation of automatic trouble-shooting, and improved ride characteristics.

Advanced materials are utilized in all designs and Fig. 5 depicts the representative use of graphite/peek in each major assembly and the associated percentage weight reduction. Through the nose cargo loading is provided on all aircraft to minimize the fuselage drag and weight.

The Turbulent flow airplanes were designed with 5 percent excess cruise thrust. Takeoff is from a

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10,000 ft (3,048 m) runway at sea level standard day conditions and the midpoint landing is on an 8,000 ft (2,048 m) or less runway at the same conditions. The HLFC aircraft were designed with 12 percent excess cruise thrust and were assumed to have turbulent flow during 6 percent of the cruise flight time to assure mission completion should weather conditions preclude the use of the suction system during short periods of the mission.

Several turbulent flow aircraft were designed with various wing sweeps and the 30 degree sweep aircraft shown in Fig. 6 was selected as the best baseline aircraft for comparison with the HLFC aircraft. The HLFC aircraft were limited to wing sweep of 20° because less leading edge cross flow effects would be encountered. If higher wing sweeps prove feasible for the HLFC aircraft, significantly reduced gross weight aircraft would result.

Both low wing and high wing HLFC aircraft were designed. Fig. 7 shows details of a low wing configuration and Fig. 8 shows a high wing design. The high wing configuration proved to be significantly lighter than the low wing design.

Comparison of the HLFC aircraft with the baseline turbulent flow aircraft produced the following percentage changes relative to the baseline:

	Low Wing HLFC	High Wing HLFC
Gross Weight	- 4.0%	- 7.4%
Fuel Weight	-13.4%	-17.0%
L/D	+18.4%	+19.2%
Required Thrust	-10.6%	-13.0%

Fig. 9 summarizes seven aircraft designed to these specifications, all compared to the baseline turbulent flow aircraft. The first four aircraft are low wing configurations. Increasing initial cruise altitude may be attractive; however, the engine by-pass ratio used in this study would have to be reoptimized.

The best overall HLFC aircraft identified in this study is the high wing aircraft with both upper and lower surface HLFC. Elimination of the lower surface HLFC appears attractive because incorporation of a combination high lift/insect shield would be feasible. This configuration is currently being flight tested in the HLFC Flight Experiment on a Boeing 757 aircraft. Use of hot air de-icing in this program eliminates the need for the liquid cleaning/de-icing system which weights approximately 7000 lbs on the aircraft in the Global Range Transport Study.

In order to evaluate the impact of increased payload on these global range aircraft, a turbulent flow transport was configured for the same mission with a payload of 212,000 lb (96,162kg). Fig. 10 presents this aircraft which has a 60% increase in payload and a 48% increase in TOGW compared with the baseline turbulent flow aircraft in Fig. 6. Similar increases would be expected for the HLFC aircraft.

ADVANCED TECHNOLOGY FORECAST

Future military transport aircraft will benefit from a wide range of advanced technology now in active development. On-going advanced technology development programs show the potential for providing significant increases in L/D, decreases in specific fuel consumption (SFC) and decreases in airframe structural weight. A list of some of the major technology developments underway in several technical disciplines is provided in Fig. 11. These research and development programs are sponsored by government agencies such as NASA and the U.S. Air Force as well as by private funding by the aircraft manufacturers and related industries. Some of the advanced technologies will be addressed as they are incorporated into the design concepts of the aircraft of interest in this paper. The design challenges and benefits from the application of advanced technologies such as laminar flow control, composite structures, and propfan propulsion are discussed in Reference 3.

Rapid development, in computational fluid dynamics (CFD) capability, coupled with advanced unobtrusive instrumentation, will provide vastly improved understanding of fundamental flow phenomena. Progress in CFD will provide for modeling of increasingly complex flows, including development of improved turbulence models and full Navier-Stokes simulation.

The key technologies include the use of advanced composite materials in both primary and secondary structures in order to achieve a weight saving of about 20 percent as predicted in previous Lockheed design system studies, Reference 4. Very high propulsive and aerodynamic efficiencies at M - 0.80 cruise conditions can be obtained by use of advanced propulsion and natural and hybrid laminar flow control. Design studies show that laminar flow control aircraft tend toward higher aspect ratio wings require active controls for gust and maneuver load alleviation and flutter suppression. Lockheed preliminary design studies of transports utilizing the advanced technologies just described will provide a cumulative improvement in efficiency of 65 percent.

Advanced electronics will continue to enhance the communication capabilities of USAF aircraft. In the future, communication systems will have security that rivals an optical link. Advances in computers, software, and artificial intelligence processes are expanding at a tremendous rate. An example is the Pilot's Associate program with advanced flight stations and smart cockpit instrumentation. A typical example of the application of advances in sensors and guidance is in an autonomous landing system for night or in adverse weather conditions. An area of special technologies is concerned with aircraft survivability and vulnerability. It is expected that significant advancements will be made in reduced radar cross sections for aircraft and in control systems that rapidly adapt to components that are damaged or fail.

Two additional design concepts which are of interest for application to future large long range transports are multi-body configurations and strut braced wings. The latter is of special interest for aircraft with high aspect ratios.

CONCLUDING REMARKS

Future military transports will benefit greatly from application of advanced materials, propulsion, flight control and aerodynamic technologies. The Hybrid Laminar Flow Control concept currently being flight tested is expected to find early application due to its favorable impact on operating costs, especially on long range missions. Advanced composites are expected to finally achieve the long predicted benefits in transport applications.

REFERENCES

1. Wagner, R.H. and Bartlett, D.W., NASA Langley Research Center; and Collier, F.S., Jr.; High Technology Corp., Laminar Flow - The Past, Present, and Prospects. AIAA-89-0989, March 1989.

2. Lange, R.H., Lockheed Aeronautical Systems Co., Application of Hybrid Laminar Flow Control to Global Range Military Transport Aircraft. NASA CR 181638, April 1988.

3. Lange, R.H., Lockheed Aeronautical Systems Co., Future Transport Aircraft Design Challenges, AIAA-84-2416, November 1984.

4. Lange, R.H., and Moore, J.W., Lockheed Aircraft Co., Systems Study of Application of Composite Materials for Future Transport Aircraft. AIAA-82-0812, May 1982.

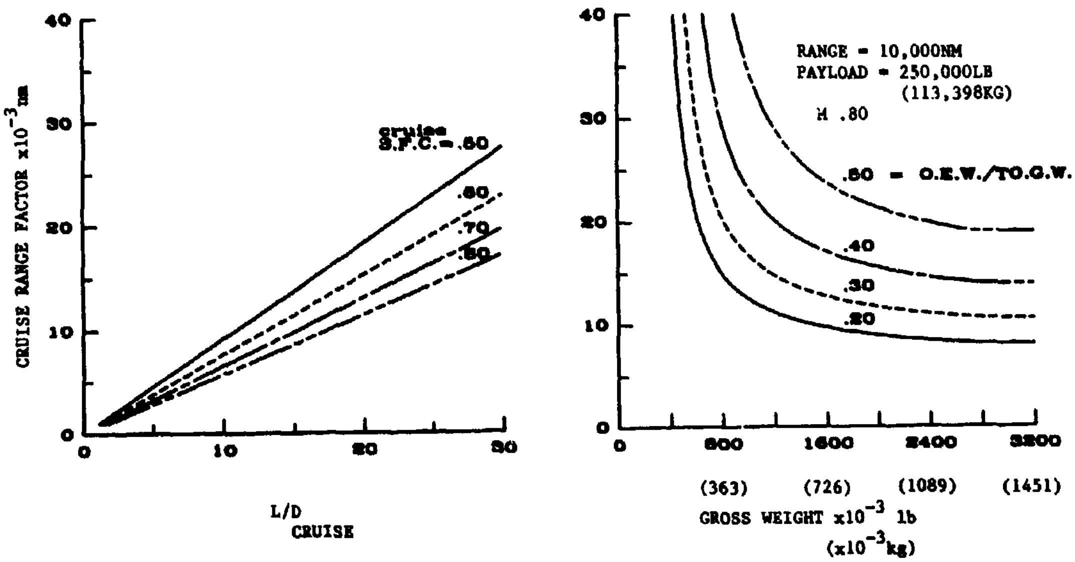


FIGURE 1. NOMOGRAPH BASED UPON BREQUET RANGE EQUATION

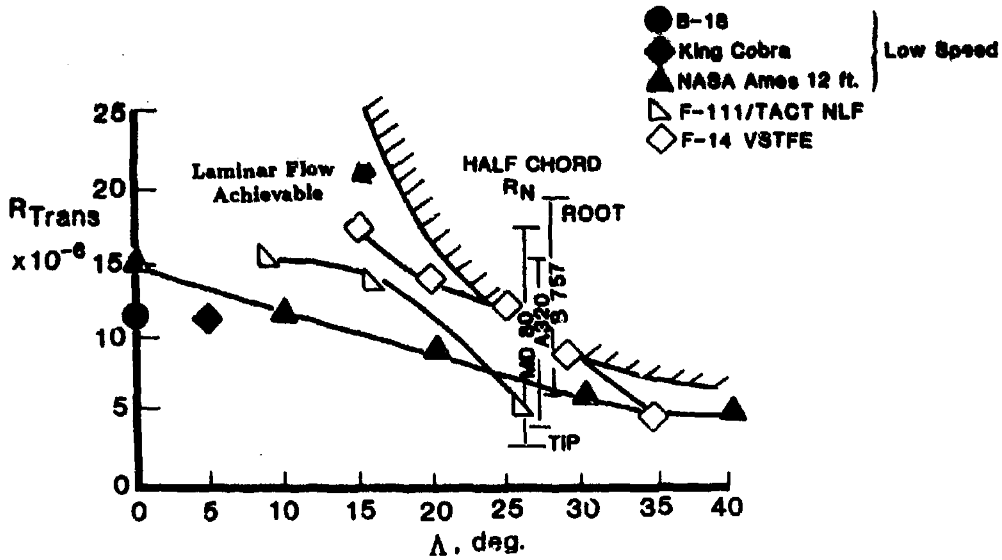


FIGURE 2. NATURAL LAMINAR FLOW TRANSITION REYNOLDS NUMBERS

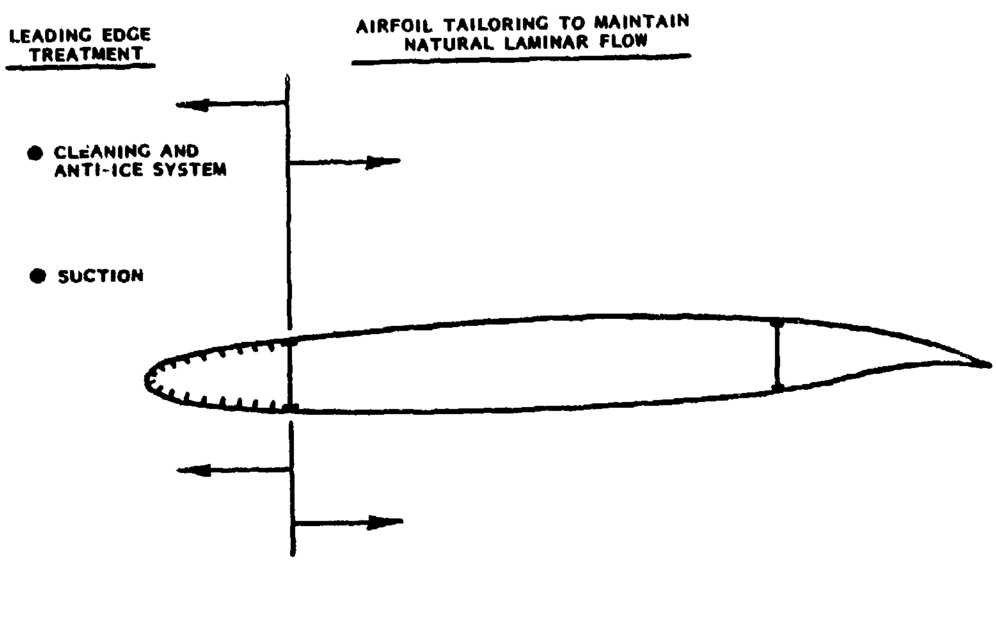


FIGURE 3. HYBRID LAMINAR FLOW CONTROL CONCEPT

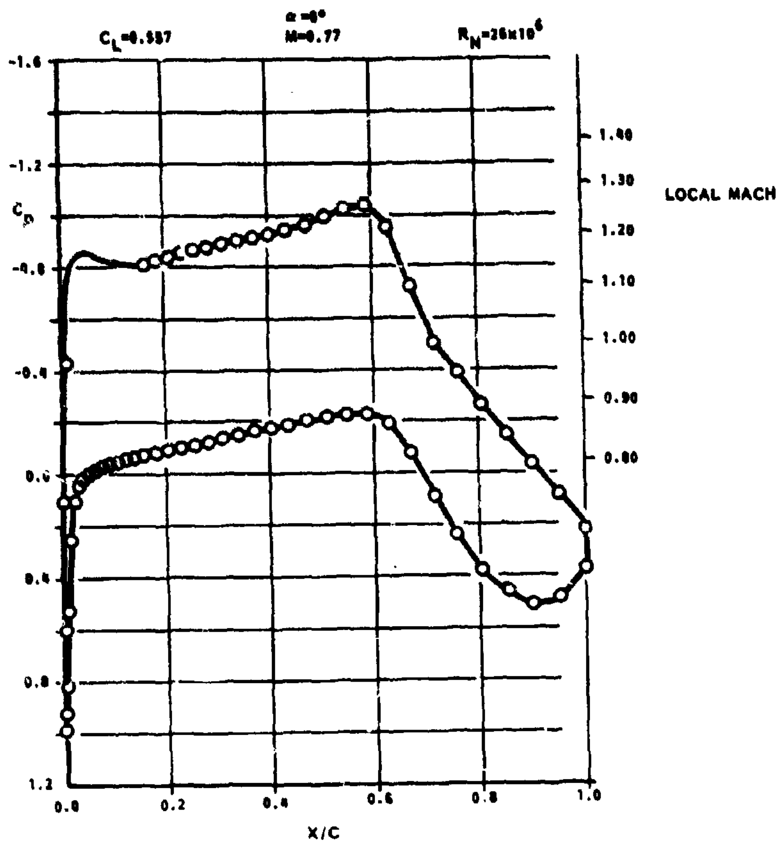
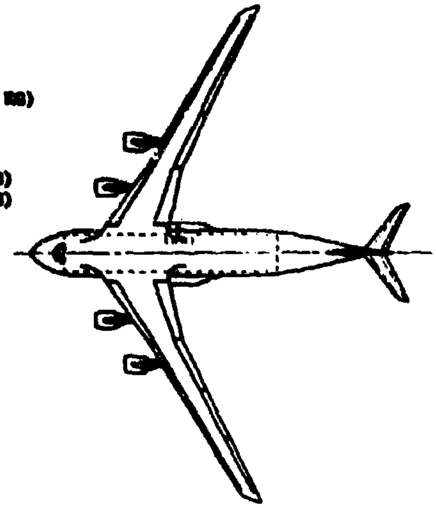


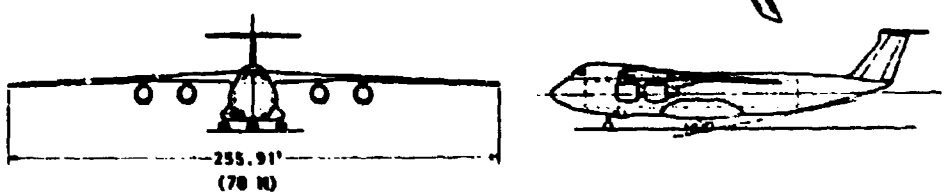
FIGURE 4. REPRESENTATIVE WING CP DISTRIBUTION FOR WING STATION =.488

STRUCTURAL COMPONENT	% GRAPHITE PEEK	% CONVENTIONAL MATERIAL	% WEIGHT REDUCTION
WING	69	31	29.5
HOZ TAIL	59	41	22.4
VERT TAIL	63	37	20.4
FUSELAGE	71	29	19.1
LANDING GEAR	27	73	11.4
NACELLE	31	69	21.0

FIGURE 5. ADVANCED MATERIAL UTILIZATION

PAYLOAD	132,500 LB (60,100 KG)
RANGE	6,500 NM*
MACH NO.	0.77
ALTITUDE	32,119 FT (9790 M)
TOGW	616,125 LB (279,470 KG)
FUEL	291,401 LB (132,179 KG)
L/D	25.99
MAC	22.80 FT (6.95 M)
SPAN	255.91 FT (78 M)
AR	13.50
C/4 SWEEP	30 DEG





*12,038KM, Off Load Payload and Return Unrefueled

Figure 6. Turbulent Flow Baseline Design Concept

PAYLOAD	132,500 LB (60,100KG)
RANGE	6,500 NM*
MACH NO	0.77
ALTITUDE	31,361 FT (9,559M)
TOGW	591,636 LB (268,362KG)
FUEL	252,218 LB (114,403KG)
L/D	30.0
MAC	22.6 FT (6.89M)
SPAN	258.9 FT (78.9M)
AR	13.07
L.E. SWEEP	20 DEG

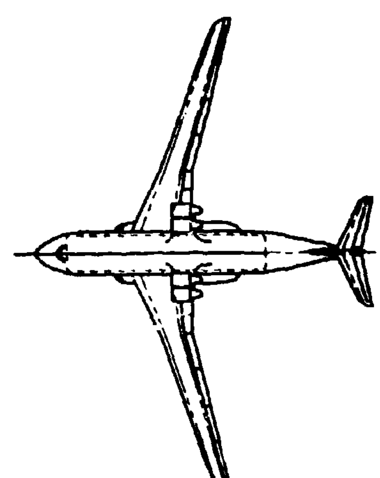


Figure 7. General Arrangement of Low Wing HLFC Aircraft

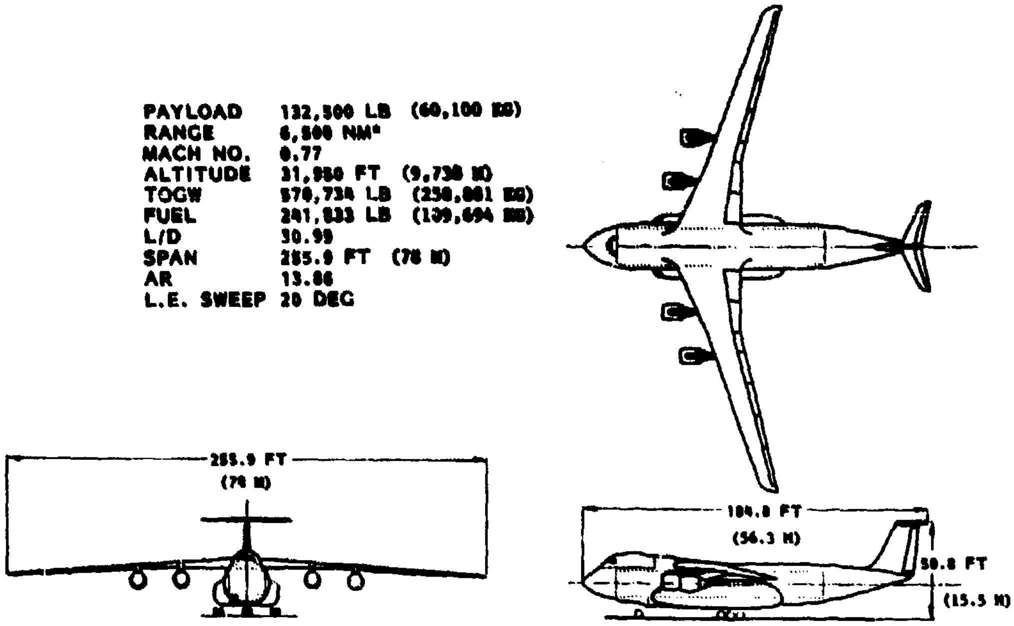


FIGURE 8. GENERAL ARRANGEMENT OF HIGH WING HLFC AIRCRAFT

CHANGE, PERCENT-RELATIVE TO TURBULENT FLOW BASELINE AIRCRAFT

	HLFC BASELINE	NO HLFC ON EMPENNAGE	NO LOWER SURFACE HLFC	ALTITUDE 36,000 FT (10,973 M)	ASPECT RATIO 10	HIGH WING ENGINES ON WING, HLFC	HIGH WING ENGINES ON WING; NO LOWER SURFACE HLFC
WEIGHTS							
OPERATING EMPTY	5.4	5.4	7.9	15.5	-0.7	0.2	1.9
GROSS	-4.0	-4.2	-0.6	-0.3	-1.1	-7.4	-4.4
FUEL CONSUMPTION	-13.4	-13.7	-7.9	-12.4	-3.5	-17.1	-11.9
LIFT TO DRAG RATIO	18.4	18.2	12.5	22.7	4.0	19.2	13.6

FIGURE 9. SUMMARY OF HLFC AIRCRAFT RESULTS RELATIVE TO TURBULENT FLOW BASELINE

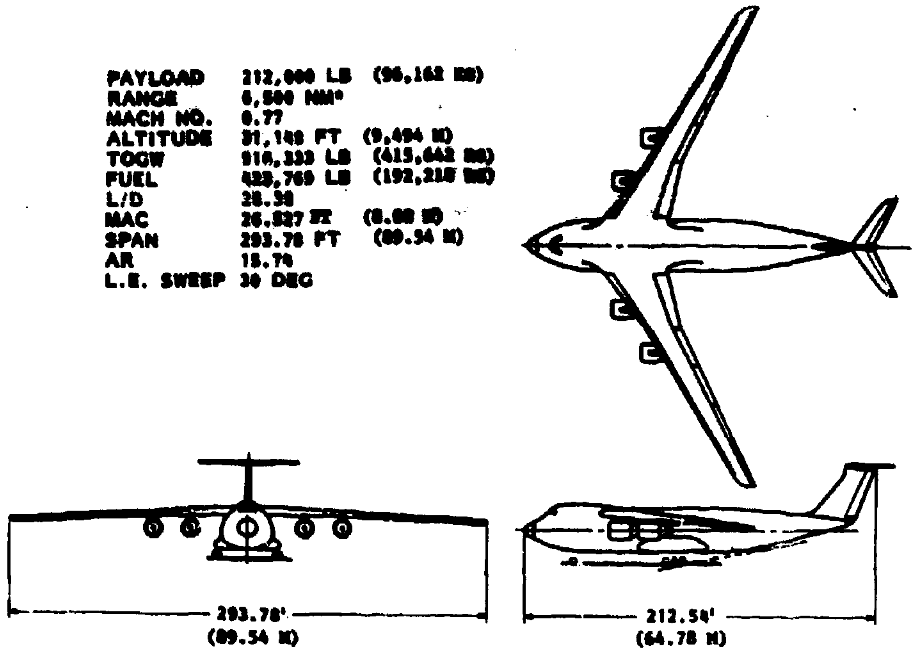


FIGURE 10. GENERAL ARRANGEMENT OF 212,000 LB PAYLOAD TURBULENT FLOW AIRCRAFT

Transport Aircraft

Aerodynamics

- Advanced Airfoils
- Laminar Flow Control
- Computational Aerodynamics

Advanced Materials

- Resin-Based Composites
- Powdered Aluminum
- Metal Matrix Composites

Propulsion

- Propfans
- Advanced Turbofans

Electronics

- Active Controls
- Electronic Cockpit
- Automatic Control Systems

FIGURE 11. CURRENT TECHNOLOGY DEVELOPMENTS

C-130 REAR VISION DEVICE (BUBBLE)

by

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In the late 1970's and early 1980's, Military Airlift Command (MAC) participation in Red Flag, Maple Flag, and other exercises provided strong evidence that airlift aircraft needed a rear vision capability for early warning and defense against air-to-air attacks. This may not be new information to many tacticians, but fresh thinking on this old idea marked a turning point for MAC.

The USAF Airlift Center (ALCENT) developed and tested three devices for providing rearward vision. The first device was a standard HC-130 observation door as used in search and rescue operations. The second device was a 180 degree field-of-view (FOV) bubble mounted on the cockpit overhead escape hatch. The third device was similar to the second, but it provided a 360-degree FOV.

The test was titled MAC Project 15-48-81. The three devices were tested at various exercises and in special sorties against fighters from Langley AFB, Virginia. The test director also consulted members of 47 Squadron, RAF Lyneham (C-130), to benefit from their experiences with observation cupolas. The test findings, published in August 1983, confirmed that the 360-degree FOV bubble proved to be the best of the three devices for warning against air-to-air attack and for observing the attacking aircraft during evasive maneuvers. 25 * Cupolas, * Vision, * Jet transport aircraft

In 1987, the Commander in Chief, Military Airlift Command (CINCMAC) elected to procure and deploy bubbles with all MAC C-130 units to include the Air Force Reserve and the Air National Guard. Each C-130 squadron was slated to obtain three bubbles. Since that decision, about one third of the required devices have been fielded.

A great deal of experience has now been gained through bubble operations. That experience can be conveniently divided into three parts: equipment, training, and tactics. The remainder of this paper will discuss those three topics and the future of the rear vision device program.

* Rear vision devices, C-130 aircraft.

EQUIPMENT

The C-130 bubble, shown in figure one, is manufactured by the plastics shop of the 438th Military Airlift Wing at McGuire AFB, New Jersey. The plastic cupola itself is made from heated and free-formed plexiglass. The rest of the hardware is made in a jig created from a surplus C-130 overhead escape hatch ring.

The bubble is fitted with a ring shaped plenum for defog air and ventilation. Once the bubble is mounted in the aircraft, the defog ring may be connected to an air conditioning duct by a short hose.

Experience indicates that the bubble works best with a few pieces of support equipment. The observer needs some protection in the form of a helmet, body restraint, and a good handhold. The helmet is standard crew issue, but the matter of a handhold and restraint is pretty much left up to individual observers. Some observers report using an ordinary cargo tiedown strap to build a sort of web. Others use a restraining harness which is standard aircraft equipment. Project 15-48-81 suggested adding a handhold to the front face of aircraft station 245, but to date, this has not been done.

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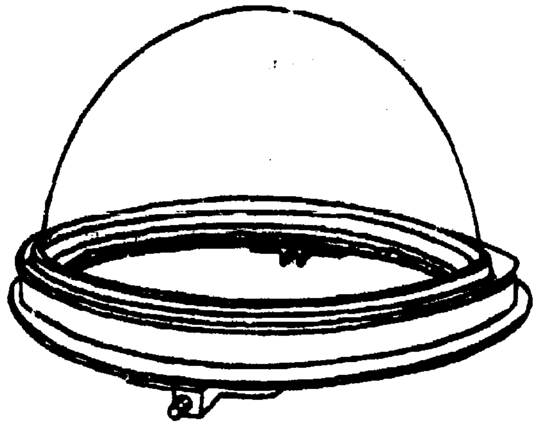

FIGURE 1
C-130 REAR VISION
DEVICE

Aircrew coordination is greatly facilitated when the observer can monitor the radios. The instructor intercom panel or a Y cord from the navigator's intercom is preferred for the observer's headset connection. If an intercom panel is added for ready access by the observer--so much the better. Stretching an intercom cord from the cargo deck is not desirable since most loadmaster intercom panels do not allow radio monitoring. There have been a couple of intercom lash-ups devised to allow the loadmaster (the most likely observer) to monitor all the radios and not just the intercom; however, these special intercom hookups are all local techniques and not in widespread use.

Finally, if the observer is to spend any appreciable time in the bubble, it must be distortion free. Bubbles with visual defects have proven to be annoying and fatiguing. A pair of sunglasses or a dark visor is also a necessity.

Until recently, ventilation has been a problem. The observer gets quite warm while sitting in the bubble, and a connection to the aircraft air conditioner has proven inadequate for good air flow into the defog ring. One enterprising squadron recently solved this annoying problem. Instead of connecting the defog ring to an air conditioner outlet, they connect it to the flare port or sextant port with a length of standard oxygen hose terminating in a short length of plastic pipe as shown in figure two. The pipe is inserted into the slip-stream. The end of the pipe is cut at an angle and turned so that ram air is fed to the bubble defog ring. The angled pipe end can also be faced aft to ventilate the bubble by drawing air out. The low pressure of the aircraft air conditioning system is no longer a problem.

TRAINING

The key to successful bubble operation is a trained observer; however, the training is not altogether simple. Royal Air Force and USAF experience both indicate that a single training sortie is insufficient for a person to acquire the necessary skills to be an effective observer. Additionally, periodic practice against aggressor aircraft is needed to maintain the various skills.

Initial training should include scanning techniques, aircraft type recognition, and estimating range to aggressor aircraft. The observer must recognise threat and nonthreat situations, and understand evasive maneuvers useful during various phases of an air-to-air attack.

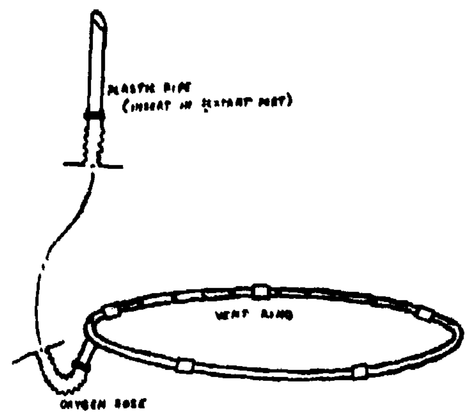

FIGURE 2

BUBBLE DEFOG SYSTEM

Observer training must emphasize crew coordination. The observer learns to pass visually acquired information to the other crewmembers using words. Concise interphone calls such as "Pilot, observer, break left, bandit at 7 o'clock." must be practiced. Furthermore, the observer must learn to time the break maneuver precisely. Calling for a break maneuver too early is a universal observer tendency, but this incorrect impulse can be corrected with training.

If a threatening aircraft flies in the dead 6 o'clock position, it will be blocked from the observer's view by the vertical stabilizer and, on some airplanes, the station keeping equipment radome. In these instances, the observer learns to request a shallow skid from the pilot to re-establish visual contact.

Note that all this scanning, estimating, and advising is done while facing aft during low altitude flight. To many observers, this is initially disorienting and confusing. The observer must overcome the discomfort caused by turbulence, heat, and the unusual viewing direction. One observer technique used to overcome the backwards directions is to write the clock positions and also the words "left" and "right" at the appropriate locations on the plexiglass as shown in figure three.

TACTICS

Specific C-130 tactics are published in a classified chapter of MAC Regulation 55-130. This paper will not discuss those specific tactics; however, there are unclassified sources that offer insight into use of the bubble.

In his book, Airlift Operations In A Hostile Environment, Lt Col John Skorupa identifies a chain of six steps that an attacking aircraft must accomplish in order to shoot down another aircraft. Those six steps are detect, acquire, track, identify, intercept, and attack. If any link in the chain is broken, the attack fails. An airlifter with a bubble and trained observer can increase the difficulty of an attacker's task at four steps in the chain, namely detection, acquisition, interception, and the actual attack--especially if it is a gun attack.

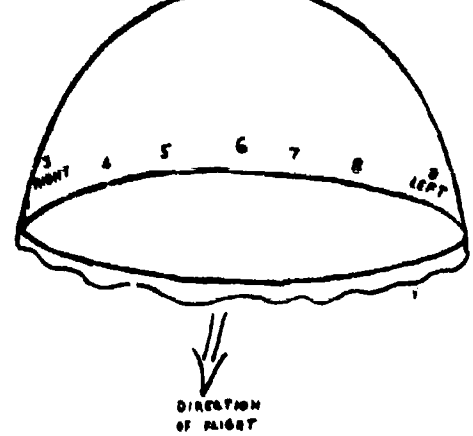

FIGURE 3
COMMONLY USED
MARKINGS

The observer should concentrate his scan on the rear hemisphere; i.e., from 3 o'clock to 9 o'clock. If the observer detects a bogey (unknown aircraft) the pilot can maneuver to decrease the chance of the airlifter being detected. This may mean terrain masking or, perhaps, keeping in the bogey's six o'clock position.

If the bogey detects the airlifter, the acquisition task can still be made more difficult by relying on camouflage at low level and by terrain masking. The observer-pilot team must work together to complicate the fighter pilot's acquisition task.

If the observer notes the bogey maneuvering for intercept, timely evasive action can seriously delay the engagement.

It is useful to point out a seemingly obvious bit of information here. It is not likely that a fighter will waste a missile on an unarmed transport if a more economical gun pass will shoot it down. Armed with that knowledge, a C-130 equipped with a bubble has a distinct advantage over a plane not so equipped. The observer-pilot team can maneuver to foil a rear approach by the fighter and significantly complicate a gun attack. If friendly fighter planes are close by, just such a simple delay might prevent an attack. The bogey must concentrate on achieving a stern firing solution against the transport plane while worrying about his own safety.

If a gun pass is unavoidable, the observer-pilot team can still make a shoot down very difficult. Again, I borrow information from Skorupa.

> "A fighter closing on a transport at low altitude and slow airspeed will have to sacrifice much of its potential energy and a portion of its kinetic energy, particularly if it intends to make a gun pass. To use its guns, it must drop to near the altitude of the target and if it does not slow down, the time available to make a gun pass is so short that its chances of success are small. This is so because an air-to-air cannon is only effective at ranges of less than 3,000 to 4,000 feet. Inside 1,000 feet, the fighter employing a cannon runs the risk of shooting itself down as it flies through shrapnel.
>
> Therefore, the window of opportunity is open only as long as it takes the fighter to traverse the range from 4,000 feet to 1,000 feet. A 500-knot fighter overtaking a 250-knot transport would enter and exit the window of opportunity in about 7 seconds. Against a nonmaneuvering target at moderate altitudes, this time would be sufficient for even the least proficient of

fighter pilots, but against a maneuvering target at low altitudes, the available time is much less."

Skorupa goes on to make a fairly convincing argument that a maneuvering transport could not only reduce the window of opportunity to about 4 seconds, but that the fighter will probably not risk multiple gun passes.

> "For example, consider a fighter making a gun pass on a transport that is flying at 300-foot altitude and 250 knots. If the fighter's cannon is inclined above centerline 2 degrees (author's note: according to Skorupa, this is a common boresight angle for several air-to-air fighters) and the fighter requires 3 degrees angle of attack to maintain level flight, its cannon will be pointed 5 degrees above horizontal. Therefore, to aim the cannon at a coaltitude target, the fighter must enter a 5 degree dive. (If the fighter starts the gun pass at a higher altitude than 300 feet, it must increase the dive angle by 1 degree for every 69.8 feet above 300 feet. Since a higher dive angle also increases the sink rate of the fighter, little is to be gained so close to the ground). Assuming the fighter begins the maneuver at 500 knots, it has about 4 seconds before it hits the ground."

To reiterate, the observer-pilot team can complicate the detection, acquisition, interception, and attack links in the chain of events required to achieve a shoot down. The added complication may be enough to discourage the attacker, or, if the attack ensues, evasive maneuvers could force a wide enough overshoot to force the fighter to begin the chain all over again. Meanwhile, the transport may be able to use camouflage and terrain masking to get away.

FUTURE PLANS

In there tight budgetary times it is always dangerous to make predictions about what equipment may be developed or deployed. Nonetheless, there are a couple of initiatives being worked by the acquisition community.

First, although it was recommended by MAC Project 15-48-81, the bubble has never been fully tested or certified to be pressurized. This is an obvious drawback as long duration "high-low-high" flight profiles can't safely use the bubble. Installing a bubble in flight is dangerous. Those who have attempted in-flight installation report that the low pressure region above the cockpit draws the bubble rapidly into the escape hatch hole with enough force to sever a finger. Efforts are under way to develop and test a bubble using thicker plexiglass or other materials that would safely withstand multiple pressurization cycles at cold temperatures.

Second, a bubble has been designed and partly tested for use on the C-141. This bubble design mounts in the aft side escape hatch and affords a good view of one side and directly behind the aircraft. It would take two such bubbles to protect the C-141.

CONCLUSION

The C-130 bubble is widely, but not universally accepted. There remain people in the airlift community who are skeptical as to the value of the bubble. Aircrews that have used the bubble at Red Flag, Maple Flag, and other exercises almost all favor getting more and improved bubbles. There is also keen interest among those who do not employ C-130s for airlift, such as airborne command posts and tankers.

As stated earlier, the bubble development is a revisit of an old idea. Many lessons, once common knowledge among aviators, are surely being relearned.

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TECHNOLOGY AND DESIGN CONSIDERATIONS FOR AN ADVANCED THEATER TRANSPORT

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SUMMARY

The Advanced Transport Technology Mission Analysis (ATTMA) program is a broad based on-going investigation of future theater airlift mission requirements and the technologies necessary to satisfy those requirements. The ATTMA study is an Aeronautical Systems Division, Deputy for Development Planning (ASD/XR) and Wright Research and Development Center, Technology Exploitation Directorate (WRDC/TX) joint initiative. This paper, which is based upon selected results of this study, addresses the design and technology issues posed by the perceived mission requirements for a twenty first century theater transport.

The theater transport of the future will be called upon to operate throughout the world in a variety of climatic conditions. In addition it will be called upon to operate into and out of remote and austere locations with unimproved runways, limited or non-existent landing aids, and in many cases no cargo handling equipment. Such an airlifter will be required to operate near, and occasionally, into enemy territory, where the threat will be far more lethal than in the past. (25) * Jet transport

The design and technology implications of these perceived requirements are discussed relative to three design/technology issues: field length, which addresses both the impact of takeoff and landing rules on Short Takeoff and Landing (STOL) aircraft design, and the impact of propulsion and vertical lift payload on Vertical or Short Takeoff and Landing (VSTOL) aircraft design; payload/aircraft size, which addresses typical theater transport payloads, productivity as a function of payload and the contribution of advanced materials on aircraft size; and survivability, which addresses the impact of low observables considerations upon theater transport design.

aircraft, * Airlift operations, Theater level organizations.

INTRODUCTION

The emerging doctrine of an integrated AirLand battlefield, which emphasizes battlefield mobility in a lethal environment, makes it necessary to reexamine the role and nature of the tactical airlifter. To accomplish this examination, ASD/XR and WRDC/TX embarked upon a program of in-house and contracted mission analyses, technology application and concept development to understand the key issues and assess their impact upon mission requirements and technology needs. The examination of future airlifter needs was conducted in the context of three notional scenarios; NATO Central Region, Southwest Asia, and Central America. The regions represented in these scenarios offer a diverse representation of geographic features, logistics infrastructure, climate conditions and threat intensities necessary for a comprehensive analysis.

To determine the relative importance of critical technologies and design issues, it is first necessary to examine current airlift operations and projected future operations. Figure (1) depicts the current airlift operations. Airlifters in theater operate out of main operating bases (MOB) into forward operating bases (FOB) and forward operating locations (FOL) with the final movement of cargo accomplished by Army surface or helicopter transport. Figure (2) depicts a perception of the intratheater airlift operations relative to the battlefield of the future. The future battlefield will require increased airlift support for small forces (battalion and company) which are continually on the move. The airlifter will be required to operate in an increased threat environment from austere airfields or non-airfields (roadways, open fields, etc,) and on both sides of the forward line of troops (FLOT). Examination of the future battlefield indicated a need exists for a short field or vertical lift capability. Questions arise as to the required field length, and the impact of field length on aircraft design? To address these issues, representative design-to mission profiles were developed and two families of aircraft were selected for analysis, STOL and VSTOL.

The primary design-to mission profiles employed in the design analysis are the Multi-Stop Assault Mission and the High Hot Assault Mission. Though other missions were considered, these missions have the greatest impact upon technology and design. Figure (3) illustrates the Multi-Stop Assault Mission. This mission is characterized by out-of-country basing, in-country payload on-load followed by payload deliveries employing assault takeoff and landing rules, no in-country maintenance or refueling

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and low altitude terrain following/terrain avoidance legs at the delivery sites. The High Hot Assault Mission, Figure (4), is characterized by a sea level hot day takeoff, cruise at 1000 feet (300 m) above ground level (AGL) to an assault landing and takeoff at 4000 feet (1200 m) runway elevation, 95 degree Fahrenheit (35°C) conditions, bracketed by 200 foot (60 m) above ground level penetration and egress legs. These design-to mission profiles represent the initial attempt at defining future theater transport missions, and as such, are being continually updated as the mission, and analysis technology assessment progress.

Figure (5) identifies a number of the aircraft concepts examined in the ATTMA study effort. Through the course of the effort three STOL powered lift techniques and six VSTOL vertical lift techniques were examined. In addition to conventional configurations, low observable (LO) configurations were also included in the study matrix. The STOL propulsive lift concepts include both turbofan and profan externally blown flap and upper surface blown propulsive concepts. In addition, turbofan lift engine concepts for low observable STOL were investigated. The VSTOL matrix included both turbofan and turboprop propulsive concepts. The turbofan propulsive concepts include lift-plus-cruise, lift-plus-lift cruise and fan-in-wing. The propeller concepts include variations of tilt wing, tilt nacelle and tilt propeller propulsive concepts. The technology and design considerations presented within this paper focus on propfan externally blown flap STOL and turboprop tilt wing VSTOL concepts.

To accomplish the examination of the box size/payload issue, three nominal box size/payload combinations were employed in the design matrix. This approach permitted the operations analyst to determine productivity as a function of box size for each STOL and VSTOL concept. Table (1) identifies these combinations for the assault condition (3g load factor) payloads. The medium box size/payload case represents the C-130 cargo box dimensions, but with an increased assault payload capability. The small box size/payload case represents a point in the design matrix characterized by aircraft that are primary carriers of palletized cargo. The large box size/payload variation represents the capability to assault airland large payloads, such as the Multiple Launch Rocket System (MLRS).

Having established a notational concept of operations, defined typical design-to mission profiles, and identified a concept matrix, the issues of field length, box size/payload and survivability can now be examined.

FIELD LENGTH-STOL TAKEOFF AND LANDING RULES

Since both a VSTOL and STOL takeoff and landing capability appear to offer distinct operational opportunities, both were examined to determine their impact upon design, technology and operations. The impact of STOL field length will be discussed first.

The STOL field length design point was established at 1500 feet (460 m), sea level standard day conditions and assault takeoff and landing rules (maximum effort). This definition of field length was established to serve as a reference about which tradeoff and sensitivity analyses can be conducted. Figure (6) depicts the assault field length. Assault rules require speed, maneuver and climb margins to be established with all engines operating. Assault rules also permit the use of maximum reverse thrust and braking during landing. The landing field length is defined as ground roll plus 300 feet (90 m). Takeoff field length is defined as the distance required to accelerate and liftoff.

The impact of the perceived requirement for a 1500 foot (460 m) STOL field length is illustrated in Figure (7), for a propfan STOL configuration which employs externally blown flap (EBF) powered lift devices. The baseline aircraft in this example exhibits a mission gross weight of approximately 160,000 lbs. (72,500 kg). Reducing the field length to 1200 feet (370 m) would incur extremely large weight penalties. The slope of the curves from 1500 feet (460 m) to 1200 feet (370 m) is extremely steep, indicating that 1500 feet (460 m) may be the shortest field length that can be reasonably considered for a STOL aircraft of this size which employs powered lift devices. The cost of a 1500 foot (460 m) field length capability is readily seen. Relaxing the field length requirement from 1500 feet (460 m) to 2000 feet (600 m) offers reductions of 13% in mission fuel, 15% in operating weight empty (OWE) and 18% in mission gross weight (GW).

Since the theater transport of the future will be called upon to operate throughout the world, the effects of runway elevation and temperature conditions must also be considered. Using sea level standard day conditions and assault rules as the point of reference, Figure (8) illustrates the effect of varying runway elevation and temperature, and landing rules upon aircraft fuel weight, operating weight empty (OWE) and gross weight (GW). If the design point is established at 5000 feet (1,500 m) runway evaluation 103 degrees Fahrenheit (40°C), in lieu of sea level standard day conditions, an increase of 8% in mission gross weight, 11% in operating weight empty and 10% in mission fuel weight is incurred. If normal operating rules at 5000 feet (1500 m) runway elevation and 103°F (40°C) were to be employed, in lieu of assault rules at sea level standard conditions, penalties of 18%, 25% and 21% to mission gross weight, operating weight empty and fuel weight respectively would be experienced. Normal operating rules permit continued safe takeoff or stopping after loss of an engine during takeoff, and continued safe landing operations or go around after the loss of a critical engine during landing, while assault require that all engines be operating. This difference has a large impact on engine size. As can be seen, the selection of field length, field length rules and atmospheric conditions have a large impact upon aircraft design weight.

Figures (9) and (10) illustrate the effect of atmospheric conditions and field length rules upon landing performance. In Figure (9), the assault landing design point is shown to be established at a 3g load factor with an aircraft landing weight of 220,000 lbs. (99,800 kg) and a corresponding field length of 1500 feet (460 m). The corresponding hot day landing performance at the same gross weight requires a field length of approximately 2000 feet (600 m). To retain the same field length performance of 1500 feet (460 m) at high hot conditions, a large reduction in aircraft payload is required. Figure (10) illustrates landing performance for the same conditions, but for normal operating rules. For the sea level standard day case, field length varies from 1800 (550 m) to 2400 (730 m) feet, while for the 5000 foot elevation (1525 m) hot day case, field length varies from 1900 feet (580 m) to 3250 feet (990 m). For the 3g load factor weight the critical field length is 2075 feet (630 m) at sea level standard day conditions and 2750 feet (840 m) at the high altitude hot day conditions.

By placing the STOL field length design point at sea level standard day conditions and assault rules, good performance is attained at high hot conditions, as well as at sea level standard conditions, for both assault and normal operation, and this performance is attained at the lowest gross weight.

FIELD LENGTH-VSTOL PROPULSION AND PAYLOAD

Operations analysis indicates that a VSTOL capability could enhance theater airlift operations by offering both an excellent emergency resupply capability and means of rapid movement of reinforcing infantry battalions. The following discussion identifies some of the design considerations and their impact upon weight and technology. The takeoff and landing field length for the VSTOL configurations is defined as 0 to 300 feet (90 m) ground roll with 1.5 minutes of hover time allotted for each takeoff or landing operation. Figure (11) summarizes the relative merits of candidate VSTOL propulsion concepts. In order to conduct comparisons of a wide variety of VSTOL concepts, the definition of "VTOL WEIGHT FRACTION" is expanded to include the installed weight of propulsion and lift engines, the weight of the fuel they consume in VSTOL operations and any other significant weight penalties relative to a conventional "cruise airplane." The curves presented indicate that the X-Wing, Lift-Cruise and Lift-Plus-Cruise concepts exhibit either high weight fractions or high exhaust jet velocities (disk loading). The Multi-Stop Assault Mission, with its multiple stops, favors the low hover fuel consumption of the Tilt Rotor and Tilt Wing class of propulsion concepts. The turbofan lift engine propulsion concepts are of interest because they lend themselves to low observables design and are later employed to assess the impact of low observable considerations upon theater transport design.

Erosion of the ground surface by the lifting engine efflux is a problem which is critical to the development of a VSTOL tactical transport, since the stated desire is to operate near to the final delivery point into unprepared austere sites. Figure (12) presents the ground erosion characteristics of typical propulsive concepts as a function of exhaust dynamic pressure of the jet sheet at the ground plane, and disk loading. Disk loading is defined as the static thrust divided by the device exit area and is a primary measure of surface erosion. The high disk loading of the turbofan lift engine concepts makes them only suitable for operation on prepared surfaces. Propeller concepts, such as the XC-142, with disk loadings of approximately 60 psf (2900 nt/sq m), are suitable for operating on wet sand, wet dirt and gravel, while helicopters, with disk loadings of 20 psf (960 nt/sq m) and lower, can operate on wet sand, dry dirt and water with acceptable surface erosion.

Since disk loading determines the suitability of a VSTOL transport to operate into forward areas, the determination of the optimum disk loading from a design perspective is of interest. Figure (13) is a notional representation of the variation in total propulsion weight as a function of propeller diameter and disk loading. The horsepower required to produce a given thrust is strongly influenced by disk loading. As propellers become larger (lower disk loading), the engine size becomes smaller. Conversely, as propellers become smaller (higher disk loading), larger engines are required. When considering these effects for a four propeller VSTOL aircraft, the lowest aircraft weight would occur at a disk loading of approximately 30 lb/sq ft (1440 nt/sq m). This optimum disk loading is not constrained by physical design limitations such as wing span, wing loading, aspect ratio and propeller diameter. When considering these constraints, the disk loading for the lightest vertical lift gross weight Tilt Wing configuration is in the neighborhood of 70 lb/sq ft (3350 nt/sq m). This is not an extremely low disk loading; however, it is adequate for austere site VSTOL operations. If lower disk loadings are desired, other propulsion-wing-airframe configurations which can facilitate larger diameter propellers or rotors, such as a dual Tilt Wing, may be considered.

The propulsion system, consisting of engines, gear boxes, shafting and propellers, and the vertical lift payload are critical to the design of a viable VSTOL configuration. Figure (14) offers insight into the effects of critical propulsion parameters upon propeller Tilt Wing design and technology needs. For this example the vertical lift propulsion system is sized for the High Hot Assault Mission with a medium payload of 33,000 lbs (15,000 kg). Significant improvement in propulsion system weight, a 52% reduction, is achieved through employing flat rated engines, propeller figure of merit (FM) of 0.75 and a thrust to weight ratio of 1.08. FM is defined as the ratio of the propeller slip stream kinetic energy rate (induced) to the input energy rate of the propeller shaft. The effect of this reduction in propulsive system weight is reflected in the aircraft parameters of takeoff gross weight and operating weight empty. For this example, the effect of a high FM and a reduced thrust to weight margin is more effective than reducing the payload by 8,000 lbs (3,600 kg).

Significant improvement in propeller VSTOL vehicle weight can be made through reductions in the propulsion system weight; however, since VSTOL transports must operate at both sea level and at higher elevations the judicious selection of the vertical lift payload is important if reasonable size aircraft are to be realized. Figure (15) depicts the impact of altitude and temperature upon vertical lift payload for the previous example. By flat rating the engines at the high hot condition aircraft gross weight is reduced, as well as the sea level vertical lift payload capability. By also reducing the payload from 33,000 lbs (15,000 kg) to 25,000 lbs (11,300 kg) gross weight is reduced further, while an acceptable vertical lift payload match across the altitude temperature spectrum is attained: 25,000 lb (11,300 kg) at 4000 ft (1220 m) 95°F (35°C), 33,370 lb (15,136 kg) at sea level 90°F (32°C), and 37,000 lb (16,780 kg) at sea level 59°F (15°C).

A VSTOL vehicle can be considered a viable theater transport alternative to a STOL vehicle if propulsion system weight reductions can be achieved, and payloads are selected to take maximum advantage of a VSTOL vehicle's STOL and VTOL capabilities. Propulsion system weight reductions can be achieved through: the use of flat rated engines, engine overboost for emergency operation, proper propeller selection and optimization of propeller design. The payload selection for a VSTOL transport could be based on three levels of operational capability: where the vertical lift payloads might be determined by emergency movements and resupply which require direct delivery; the STOL payloads, which are larger, might be determined by the requirement for operations into forward austere strips; and the maximum payload, might be determined by the largest item to be transported, such as the MLRS, and be accomplished at a reduced load factor.

AIRCRAFT SIZE AND PAYLOAD

The payload/box size capability of a future theater transport must be determined within the context of the theater in which it will be operating. In addition, consideration must also be given to the other airlifters that may also be operating in the same theater. In the case of an Advanced Theater Transport, the C-17's may also be operating in the same theater. Figure (16) is an example of the interdependent nature of the payload/box size issue. This figure presents, for the European Theater, the increase in productivity for families of the small, medium and large Advanced Theater Transports. The data presented was produced by the Generalized Airlift Mobility Model (GAMM), developed specifically for the evaluation of theater transports, and is representative of a notional thirty day scenario. The percentage of Total Tons Delivered over a thirty day period is compared for varying fleet mix ratios of C-17 aircraft, with either Advanced Theater Transport STOL configurations or C-130 aircraft. This figure indicates that box size/payload for a future theater transport may be dependent upon C-17 aircraft availability and its short field capability. To achieve acceptable effectiveness with minimum numbers of aircraft, the medium or large payload box size combinations may be preferable since more C-17's are required to compensate for the small box size configuration. The medium and large configurations can carry the largest piece of equipment, the Multiple Launch Rocket System: the large box size variants at a 3g load factor (assault conditions) and the medium box size variants at reduced load factor of 2.5g's.

The payloads that tend to size a future theater airlifter are the: ammunition pallets (463L pallet system), the Multiple Launch Rocket System (MLRS), the Palletized Loading System (PLS) flatracks and the M198 Howitzer with truck. Figure (17) depicts these items. The MLRS, at 57,400 lbs (26,000 kg) and 9.75 feet (3.0 m) wide, establishes the maximum payload and the minimum cargo box width. The M198 howitzer and truck establishes the minimum cargo floor and ramp length. The PLS flatrack offers an interesting problem to the designer, in that, the cargo loading rack 8 ft x 20 ft (2.4 m x 6.0 m) weighting 37,000 lbs (16,800 kg) when fully loaded. The PLS flat flatrack is primarily designed to be PLS truck transportable, but it is envisioned that the need may arise to air transport PLS flatracks in the future.

The contribution of advanced materials upon aircraft size and weight is significant for both STOL and VSTOL configurations. The impact is largest upon VSTOL designs where the larger propulsion system weight fractions more rapidly grow the mission gross weight. Figure (18) offers an insight into the contribution of advanced materials to aircraft weight for a medium payload box size externally blown flap (EBF) propfan STOL configuration and a low observable turbofan VSTOL configuration. Two cases are examined: direct substitution of advanced materials into a design originally sized for conventional materials (not resized), and the resized case, where advanced materials are the initial material of choice. The primary advanced materials utilized are aluminum-lithium and a carbon filament reinforced plastic (CFRP). Direct material substitution results in a structural weight reduction of approximately 26% for both the STOL and VSTOL examples, and gross weight reductions of 20% and 28% respectively. These weight reductions are impressive; however, the true impact of advanced materials can be seen in the case where the example configurations are resized. In the resized case, the STOL configuration exhibits a 47% reduction in structural weight and a 30% reduction in mission gross weight. Larger weight reductions are achieved for the VSTOL configuration where a 50% structural weight reduction and a corresponding 35% mission gross weight reduction are to be found. The STOL example employs 44% advanced composites which accounts for 74.4% of the total weight reduction. The low observable VSTOL configuration is composed of 44.8% advanced composites which accounts for 62.5% of the structural weight reduction. When all composite materials are accounted for, the total composite content is 55% for the STOL and 65% for the VSTOL. The use of advanced materials can significantly impact the payload range performance, the payload field length performance, and the physical size of the theater transport. The achievement of these benefits is, however, dependent upon the producibility of large composite structures, the battle damage tolerance of the selected composite material, and the composite material's battle damage repair characteristics.

SURVIVABILITY

The theater airlifter of the future will be called upon to operate into and near a wide variety of threats not previously experienced by transports. These threats include small arms, air-to-air missiles and cannon, artillery, surface to air missiles (SAM's) and the hand held IR SAM's. Survivability enhancements must be considered in the design of an airlifter since they are critical to both mission completion and aerodynamic efficiency. Consideration must be given to both the susceptibility and vulnerability components of survivability. From the vulnerability perspective, the future theater airlifter must be capable of sustaining battle damage and continue to operate. Thus the reduction of vulnerable area through hardening, shielding of critical components, inerting, and dual path techniques must be included in the initial design process. The impact of low observable technologies upon design and mission success also is an important issue. Figure (19) provides a comparative view of the impact of low observable design considerations upon aircraft weight. The LO STOL, VSTOL and LO VSTOL examples employ turbofan lift engines. The selection of turbofan lift engines is predicated upon low radar cross section considerations. The cost of low observability is presented as a percentage weight increase relative to conventional STOL and VSTOL designs. The radar cross section of the LO configurations is several orders of magnitude lower than that of the propfan STOL example. Both the LO STOL and LO VSTOL examples exhibit approximately a 25% increase in mission gross weight over their conventional counterparts. The penalties incurred in fuel weight and operating weight empty are also significant. These large weight penalties can be attributed primarily to radar cross section considerations.

TECHNOLOGY RECOMMENDATIONS AND CONCLUSIONS

The ability of future theater airlifters to operate nearer to the FLOT and to operate into many short austere fields, that were inaccessible to theater airlifters of the past, is in great part due to the advancements in light weight composite materials and the specific fuel consumption of advanced propfan and turboprop engines. To effectively utilize the potential gains in short field operating capability, several subsystem capabilities and associated technology developments are required.

The future theater airlifter must locate the landing site, execute a landing, offload its cargo and depart. To locate the landing site a precise navigation system is essential. Such a system, in addition to inertial elements, most likely will utilize the Global Positioning System (GPS) and a digital terrain map. The ingress and egress legs to the delivery site will be conducted at low altitude, thus requiring a terrain following and terrain avoidance capability. In the likelihood that more than one aircraft is involved in the mission, the need will exist for a formation flight capability. Such a formation flight capability must afford safe aircraft separation at higher altitudes and during terrain following and terrain avoidance flight. To minimize the threat to the aircraft over the delivery site, during airdrop operations, the formation flight system should be capable of time sequencing deliveries from differing headings. For airland operations into austere or forward sites an on-board autonomous approach and landing guidance system will be required. Additionally, as STOL/VSTOL transport operations "break free", from know established airfields, there will be an increased need to determine the suitability of landing sites of opportunity. Perhaps the most critical need generated by the ability to operate into forward areas is an on-board cargo handling capability. Forward and austere sites will have limited or no ground handling equipment. The operators of the theater transport of the future will be faced with the problem of directly transferring cargo onto a variety of surface vehicles, and off-loading cargo in a rapid manner into precise locations.

In addition to the operations-driven technology needs, technology development is needed for reliable and lightweight transmissions and cross shafting for propeller VSTOL concepts. The state of the art for convertible rotors is currently represented by the rotors on the V-22 aircraft. Additional research is needed to optimize the performance and weight of props/rotors operating in the size, disk loading and speed ranges of a future theater airlifter.

The material presented in this paper is a product of the first iteration of a process directed to understanding the future theater airlift problem. As such, design-to missions and specific configurations are employed to gain insight into design impacts and technology development needs. Future work will involve the refinement of mission requirements and design rules, and a more detailed assessment of both STOL and VSTOL technology needs and benefits.

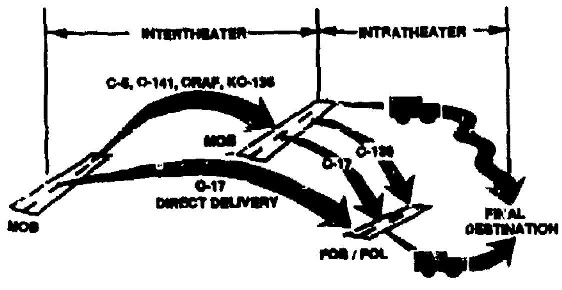

FIGURE (1) CURRENT AIRLIFT OPERATIONS

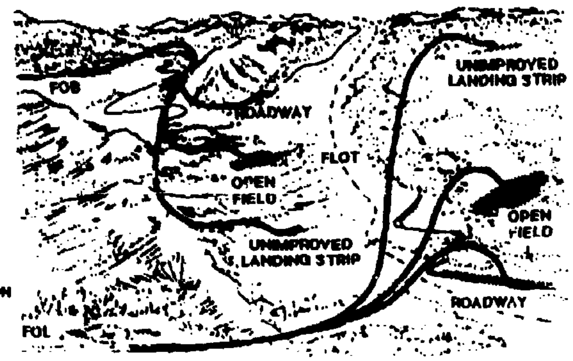

FIGURE (2) FUTURE THEATER OPERATIONS

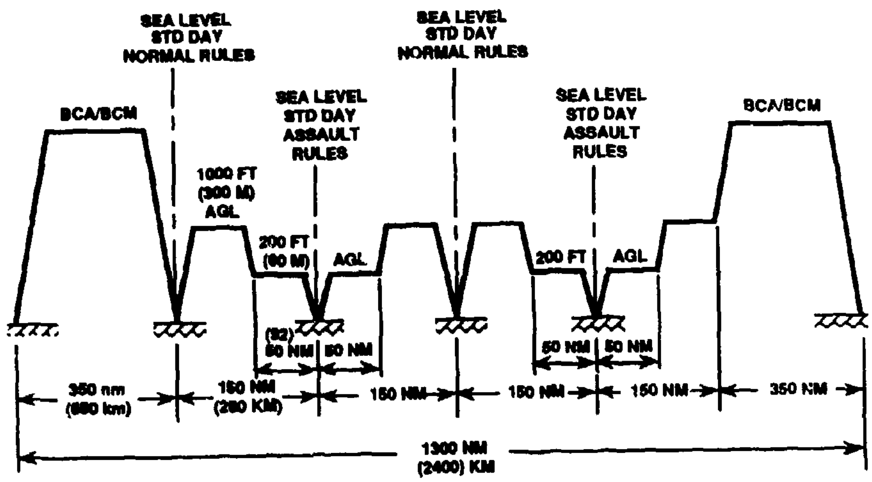

FIGURE (3) MULTI -STOP ASSAULT MISSION

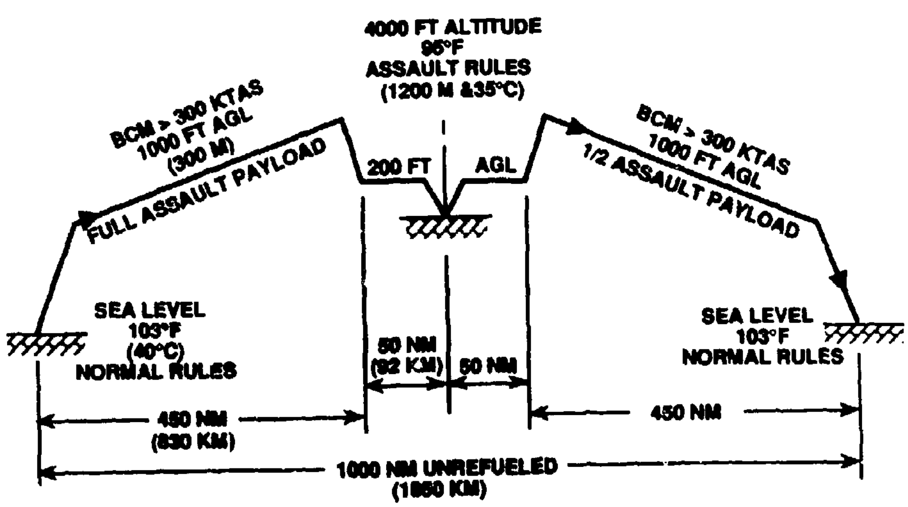

FIGURE (4) HIGH HOT ASSAULT MISSION

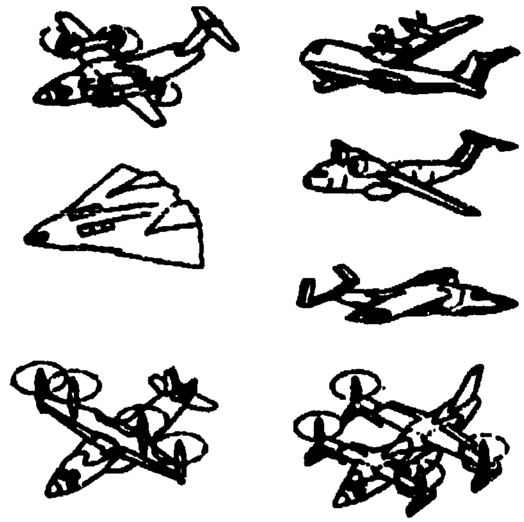

FIGURE (5) TYPICAL ATT CONFIGURATIONS

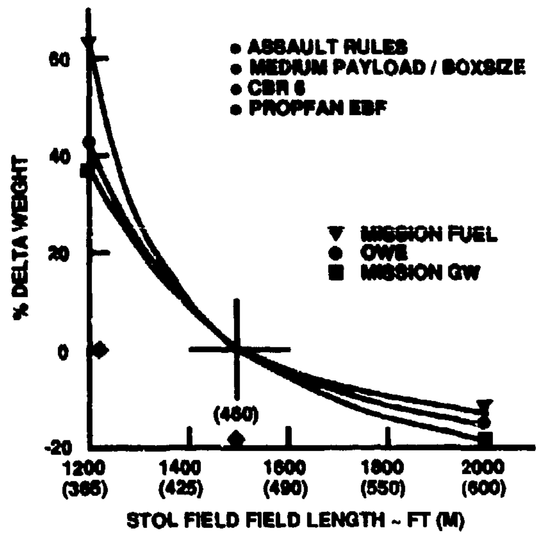

FIGURE (7) STOL FIELD LENGTH SENSITIVITY

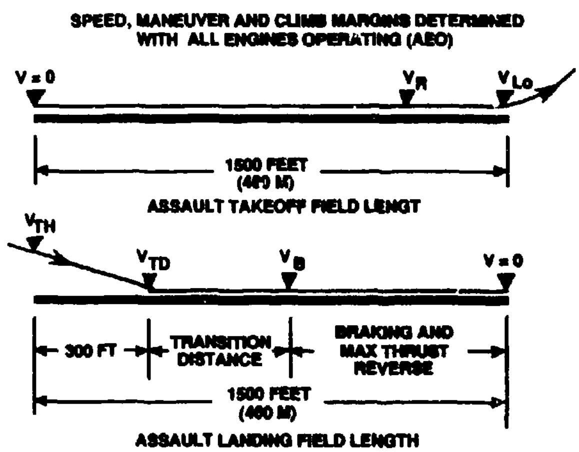

FIGURE (6) STOL ASSAULT FIELD LENGTH

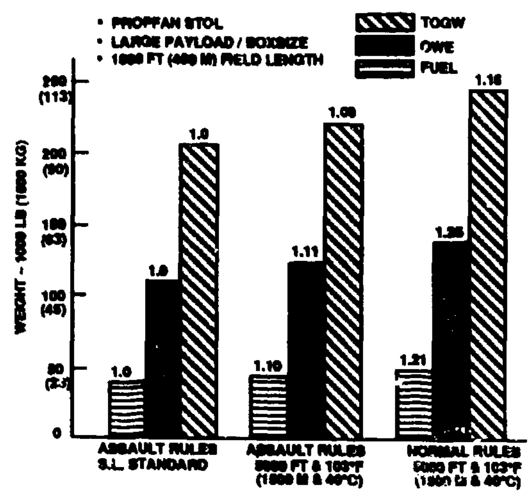

FIGURE (8) ASSAULT AND NORMAL TAKEOFF AND LANDING IMPACT

		SMALL	MEDIUM	LARGE
3g PAYLOAD LB (KG)		25,000 (11,300)	33,000 (15,000)	57,000 (26,000)
BOX SIZE FT (M)	H	9 (2.7)	9 (2.7)	12 (3.7)
	W	10 (3.0)	10 (3.0)	12 (3.7)
	L	33 (10)	41 (13)	47 to 61 (14 to 19)

TABLE (1) BOX SIZE / PAYLOAD STUDY MATRIX

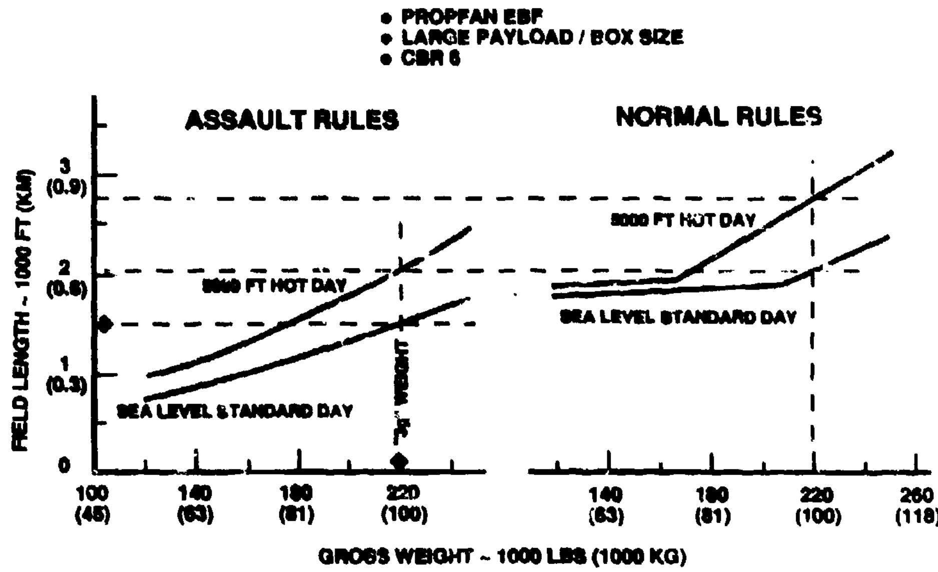

FIGURE (9) STOL ASSAULT LANDING PERFORMANCE

FIGURE (10) STOL NORMAL LANDING PERFORMANCE

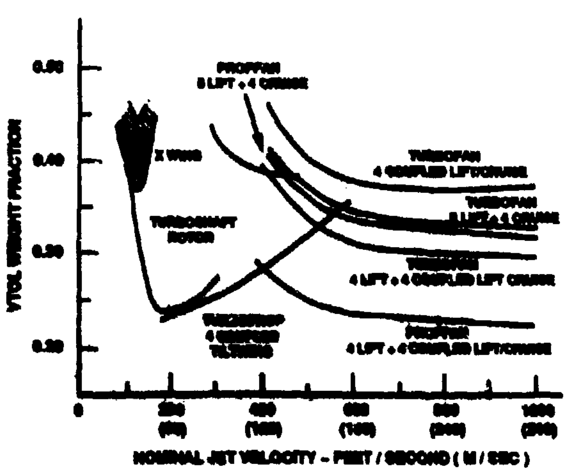

FIGURE (11) VSTOL CONCEPT SCREENING

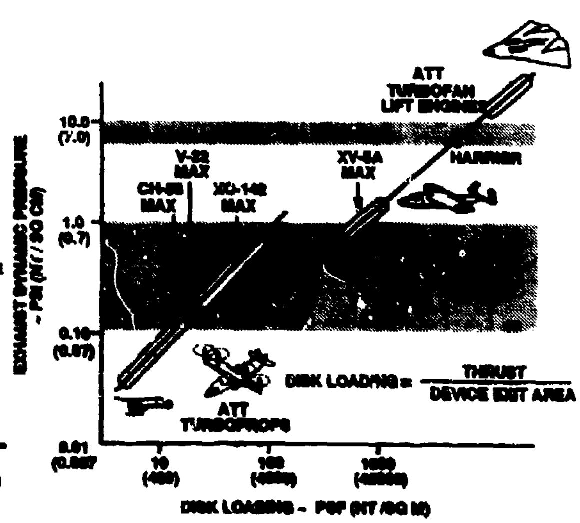

FIGURE (12) EROSION DISK LOADING RELATIONSHIP

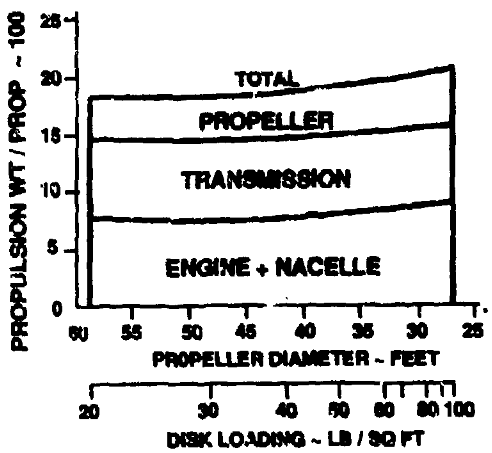

FIGURE (13) UNCONSTRAINED DISK LOADING

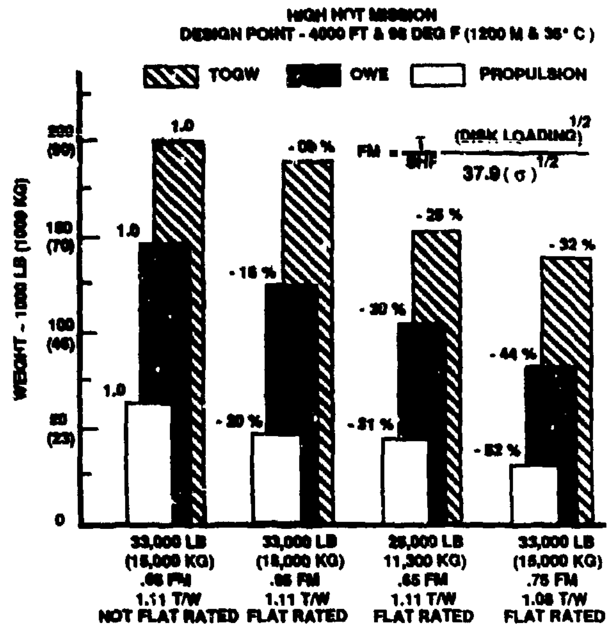

FIGURE (14) VSTOL PROPULSION IMPACT

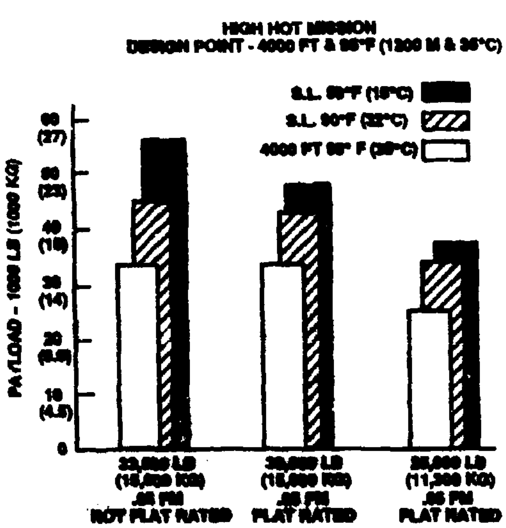

FIGURE (15) VSTOL PAYLOAD IMPACT

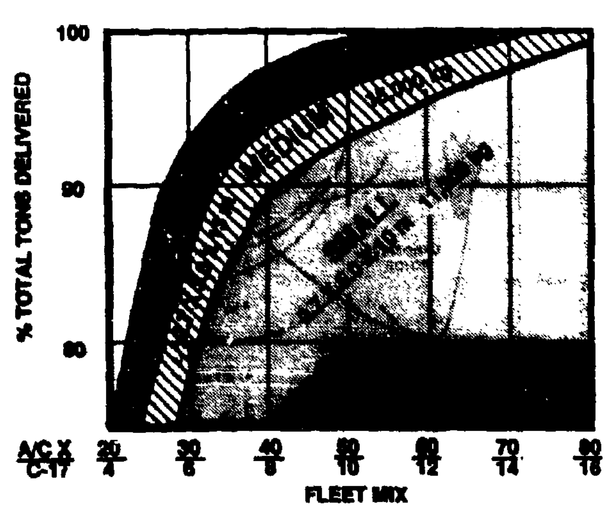

FIGURE (16) STOL PRODUCTIVITY
EUROPEAN THEATER

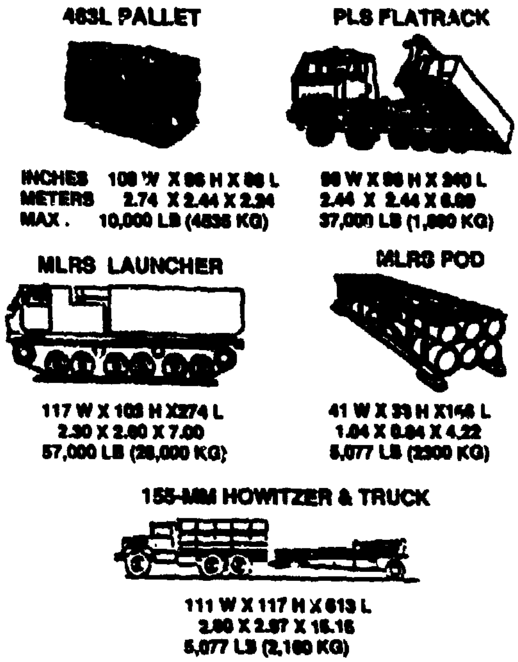

FIGURE (17) PAYLOADS

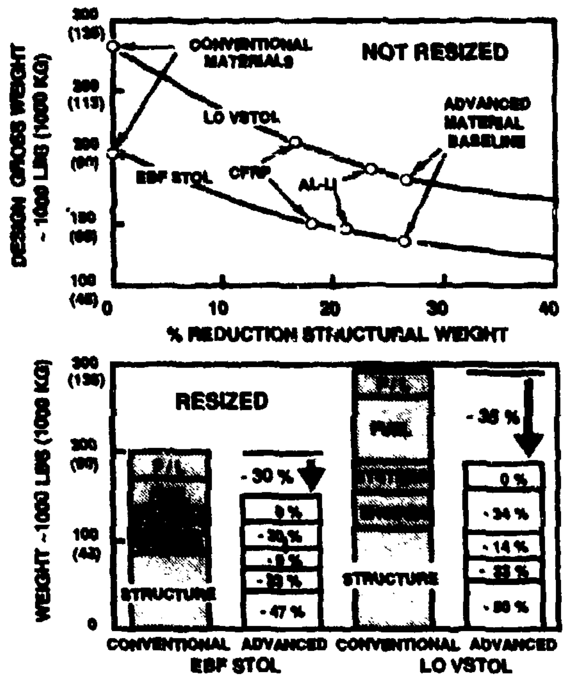

FIGURE (18) ADVANCED MATERIALS IMPACT

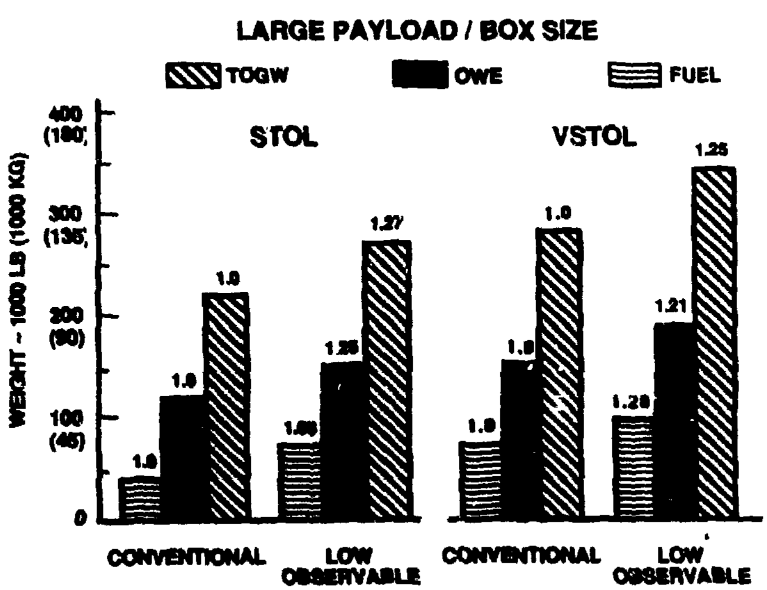

FIGURE (19) LOW OBSERVABLES IMPACT

APPLICATION OF CIVIL AIR TRANSPORT TECHNOLOGY TO MILITARY AIRLIFT

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SUMMARY

Due to a strong market demand and competition the civil passenger aircraft have improved considerably in performance and operating cost in the last 30 years. These improvements were achieved mainly by progress in technology.

Comparable improvements were not reached in military airlift. The military transport aircraft in operation today are of older design.

Civil and military transport technologies are identical to a large extent. Therefore, application of the advanced civil transport technology to a new military transport aircraft promises a leap in performance improvements and operating cost reductions. Moreover, changes in tasks and requirements can be incorporated in a new design.

The example of an advanced medium tranport aircraft shows promising indications of the improvements which are possible by applying civil transport technology and encourages further investigations.

25 * Military aircraft, * Aircraft ...
* Civil aviation, * Jet transport a...

1. INTRODUCTION

Civil passenger aircraft have developed enormously in the last decades. This is true for large commercial jets as well as for smaller turboprop planes for regional/commuter services.

The reasons for such, in some respect dramatic advancements are the market demands together with a strong competition in this market sector. The regular passenger air traffic has increased strongly over the years; e.g. the seat-miles flown in regular passenger air traffic have more than quadrupled in 20 years (fig.1). This increase in traffic has led to a great demand for aircraft. In ten years (1978 - 1988) a total of about 7200 civil transport aircraft were built (4100 jets + 3100 props).

Especially for the regional/commuter market the aircraft manufacturers offered several aircraft models, and a rather strong competition took place (fig 2). As a consequence thereof and in order to better fulfil the needs of the market, e.g. lower operating cost, better fuel consumption, low noise, improved passenger comfort etc. new technologies had to be developed and applied to the new aircraft types.

Therefore, a vast variety of aircraft models have appeared on the market, especially in the last twenty years and a number of new models are under development (fig. 3). Because of the predicted further steep increase in market demand for civil aircraft the strong competition will continue with the necessity for the aircraft manufacturers to push ahead new technologies and to develop new aircaft models.

This competitive race has not taken place in the military air-transport field. On the contrary, if the medium tranport is considered for 20 years no new development was carried out (military derivatives of civil passenger airplanes are not taken into account here).

Such aircraft as the C-160 "Transall" are still in operation in the armed forces.

Therefore, in applying the achievements in the civil field to military airlift both drastic performance improvements and operating cost reductions can be expected.

The following chapters concentrate on turboprop aircraft technologies, which still seem to be most suitable for a new advanced medium transport aircraft.

2. PROGRESS ACHIEVED IN CIVIL TRANSPORT AIRCRAFT

The progress in civil passenger aircraft can be shown in terms of reductions in overall drag and weight, improvements in performance, safety, reliability and maintenance with the main result of the reduction of the operating cost and will be discussed subsequently. These achievements are due to the application of advanced technologies in the fields of flight physics, materials and structures, equipment and avionics as well as to improved procedures in air traffic and aircraft handling and will be outlined in chapt. 3.

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The term: " Max take-off weight x max.cruise speed/installed engine power " is essentially proportional to the lift/drag ratio of an aircraft under max. cruise conditions and can be taken as a measure for the overall efficiency of an aircraft. This term has been increased by about more than 30% in 20 years (fig. 4).

The advances in weight reduction can be shown by the ratio of "Operating weight,empty/number of seats" (fig. 5). This ratio depends strongly on the max. cruise speed of the aicraft. But for approx. the same design cruise speed a weight reduction of about 20 % can be assumed in the last 20 years. This result was achieved in spite of weight adding because of additional certification requirements, increased passenger comfort by better accomodations, more spacious cabins and cabin noise improvements.

In the same time and following market requirements the max. cruise speed was increased lately from appr. 180 knots to more than 330 knots or appr. 70% (fig. 6).

The safety of air traffic improved by a factor of appr. 6-8. (fig. 7). For jet transports the number of accidents decreased from an average of 6-7 accidents/million departures in the 50ies to an average of only 1-2 accidents/ million departures in the 80ies.

The maintenance labour cost for a typical regional airliner could be reduced from 1966 to 1989 by 66 % due to better technology but also improved methods (fig.8).

In consequence of these various improvements the operating cost of civil passenger airplanes could be reduced continuously over the time by 25-35% every ten years or from 1950 to 1990 by appr. 75 % as shown in fig. 9 for jet transports.

The examples shown demonstrate convincingly the tremendous progress achieved in civil airtransport in the last decades.

From this one can deduct already that for a new military transport operating cost reductions in the range of 40 - 60 % against those of existing military transports seem to be possible.

3. OUTLINE OF ADVANCED TECHNOLOGY FOR CIVIL TRANSPORT AIRCRAFT

How were these advancements attained as shown in the foregoing chapter; what progress in the various technology fields of aeronautics and what further developments can be expected? To answer this questions only some examples can be given in the following.

Configurations

The overall layout of the aircraft as it is reflected by the aircraft configuration influences to a large extent performance and cost. As shown already in fig. 2. modern turboprop aircraft mostly still show the classical kite configuration with the engines mounted to the wings and appear to be the best solution. However, immense detail optimization was accomplished for reducing aerodynamic drag by better shapes (front/aft fuselage,wing/fuselage fairing,landing gear fairings), and by improved overall finenessratio (manufacturing tolerances, avoiding of disturbing rivetings and skin-joinings etc).

Aerodynamics

The progress in aerodynamics was achieved mainly through better understanding of the flow phenomena and made possible by highly developed calculation methods (semi-empirical and theoretical) using high performance computers and by the testing in advanced wind tunnels. It is possible to simulate and calculate the flow field around complete aircraft configurations with relatively high accuracy (fig.10).

Regarding the wing design the wing sections can be designed to specific requirements. Essential transfers were made from supercritical or transsonic wing section developments, which originally were targeted to military combat aircraft. With respect to civil aircraft a main objective of such developments was to reduce wing section drag for cruise conditions (fig.11). In addition, improvements were achieved by more sophisticated wing planforms especially concerning the wing tip shape in order to reduce the induced drag (winglets, strakes, etc). The laminar wing technology currently under development promises a further drag reduction in the order of 10-20 % with fuel savings depending on the final solution in the order of 5 - 10 %. In the case of regional/ commuter aircraft a natural laminar flow solution with a wing of no or moderate sweep seems to be feasable. The technology work carried out so far in Germany has shown encouraging results in this respect (fig.12).

Utility/commuter aircraft are sometimes required to operate from or to smaller airfields with relatively short runways, e.g. London STOL-port, operation to Greek islands etc.. Moreover, rough field operation from less prepared sites are sometimes required. Therefore, some of these aircraft have astonishing capabilities in this respect (fig.13).

Propulsion

The propulsion system has contributed substancially to the improvements achieved in civil passenger aircraft. The turboprop engine has gained special attention again for the regional/commuter aircraft because of the lower fuel consumption in comparison to jet engines. A number of newly developed engines was offered by the engine manufacturers in the course of the development of such aircraft as ATR 42, Saab SR 340, Dornier 328 and others.

The efforts to improve the engines concentrated to a large extent on reducing the specific fuel consumption. A reduction of about 40 % was reached (fig.14). Other remarkable improvements are related to reliability and maintenance cost.

Concerning the propeller development the improvements attained were through better aerodynamic design and structural layout of the blades, leading to higher efficiency and lower specific weight. Fig. 15 shows the improvements in efficiency of advanced propellers for medium and high speed subsonic aircraft in comparison to conventional propellers. Especially the counterrotating propfan is very promising for a next generation turboprop aircraft.

Materials and Structures

The development of advanced materials e.g. reinforced fibre composites was pushed ahead originally for the military combat aircraft, because of the priority given to high performance goals, which exist in this aircraft field. Therefore, the application of new materials and related structures is most advanced here, especially also for primary structures. In the civil field, cost and certification aspects are playing a more important role.

Composites structures are introduced widely for secondary structures; for example some landing flaps of the Airbus show a carbon fibre composite structure. But the application for primary structures is still relatively limited, e.g. the outer wing of the regional aircraft ATR 72 is a carbon fibre composite structure.

It can be expected that in next generation aircraft composites structures will be used to a higher extent including possibly a composite fuselage.

As known, the new materials have a tremendous potential in various parameters as for example in tensile strength (fig.16). This potential cannot be reached completely for the complex structures of aircraft, but weight reductions in the range of 20-25 % has been accomplished. Because of the higher cost of the composite materials the development of new structures has to concentrate on lower cost manufacturing methods. The development shows a trend towards still more integrated structures and automated processes.

In order to give some examples of modern structures for regional aircraft, fig. 17 shows the wing panel of the Dornier 228 which is an integrally milled AL-alloy structure; not only the stringers but also the rib caps are integrally milled. The number of parts and rivets is drastically reduced leading to a large cost reduction for tooling and wing assemblying.

The airframe of the new Dornier 328 will consist with 20% of nonmetallic structure (fig.18). The horizontal and the vertical tail spars are in carbon fibre composites. The vertical tail spar and the fuselage attachment frame are produced in a single manufacturing process, thus leading to a weight saving of appr. 25% with production cost very close to those of a comparable metal construction.

The carbon fibre composite technology for the next generation aircraft is in progress both with regard to wing and fuselage. In connection with the development of a new laminar wing the concept of a carbon fibre composite wing is developed and the necessary structural tests carried out. In the course of a technology programme for a new fuselage a CFRP fuselage test sample was built and tested. Up to 250.000 flights were simulated without any problems concerning the structural integrity of the integrally stiffened CFRP-cell (fig.19). Based on these results further efforts are concentrating on obtaining the design goals of a reduction in weight of 15 % and in production cost of 5 %.

Important advances have been reached also in the development of corrosion resistant materials and surface technology which lead to higher service life and lower maintenance cost.

Integrated control technology

Integrated control technology (ICT) deals with the problems of flight control and includes topics like:

+ Fly-by-wire/ fly-by-light technology,
+ Advanced autopilot technology (4-D-Nav., autothrottle,autoland),
+ Active control technology.

There are increasing interfaces to the avionic system concerning functions like

+ Flight management system
+ Communications systems
+ Cockpit technology

Therefore a strong interdependence exists between integrated control technology and avionics.

The integrated control technology has potential to reduce operating cost, to increase flight safety and to improve passenger comfort.

The most advanced commercial aircraft in this respect is the Airbus A320 with its fly-by-wire system. The application of ICT in regional/commuter aircraft is still very limited due to the fact that for these aircraft less costly solutions must be found in order to end up with a reduction in operating cost.

However, it is generally expected that the next generation regional aircraft will make higher use of the integrated control technology.

Avionics

The progress in modern electronics has led to dramatic changes in architecture and hardware of the avionic systems. Volume, weight, reliability, maintainability and operating cost could be reduced considerably. For example, volume and weight of typical avionics computers were reduced both by a factor of about 4 (fig. 20).

The trend is an increasing degree of integration between the different subsystems or functions including also basic systems e.g. the hydraulics system for condition monitoring, fault detection etc..

The changes in the lay-out of the cockpit and especially in the instrument panel show the development in this field in a most impressive way. As an example for a regional aircraft the advanced glass cockpit of the Dornier 328 is shown (fig. 21).

The avionics system of the Dornier 328 is a totally integrated Honeywell system, using the Avionics Standard Communication Bus (ASCB) and a Radio System Bus (RSB). It is comprised of the following major subsystems and LRU's:

* Integrated Electronic Display System (EDS)
  - 2 Primary Flight Displays (PFD)
  - 2 Multifunction Displays (MFD)
  - Engine Indication and Crew Alerting (EICAS) Display

* Guidance and Display Control Panel

* Integrated Avionics Computer (IAC) containing:
  - Power Supply
  - Buscontroller
  - Input/Output Interface
  - Display Electronic Interface
  - Fault Warning Computer
  - Automatic Flight Control System (AFCS) Computer (single basic, dual optional)
  - Flight Management Computer System (optional)

* Digital Air Data Reference Units
* Attitude and Heading Reference System (AHRS)
* Data Acquisition Units (DAU's)
* Radio and Weather Radar Subsystems
* Inertial Reference System (optional)
* Traffic and Collision Avoidance System (optional)
* Lightning Sensor System (optional)

Due to the high dependence of modern aircraft on electronics this equipment must be safe and be protected against external high energy electromagnetic radiation (HERF/EMI environment).

The Do 328 will be the first regional aircraft in its class, which will be certificated according to these new certification requirements.

Integrated effect of technology development on civil turboprop aircraft

The progress in the various fields of technology as shortly outlined in the foregoing subchapters can be combined to an integrated effect for a next generation turboprop. According to the investigations carried out the following improvement potential in comparison to current aicraft technology can be assumed (fig.22):

- Laminar wing technology:	15% drag reduction
- Propulsion - engines :	9% lower SFC
- propellers:	8% better prop efficiency
- Materials and structures:	26% structural weight reduction
- ICT and avionics:	1% MTOW reduction

The resulting operating cost reductions depend strongly on the specific project and application. The combined effect of the various improvements can be shown, if the take-off weight of two aircraft are compared which are designed to the same requirements, but differ in technology status (fig. 22). The comparison shows a take-off weight reduction of about 17%; this reduction corresponds to about 72% of the payload.

4. COMPARISON OF PASSENGER AIRCRAFT WITH MILITARY TRANSPORT AIRCRAFT

In order to answer the question to what extent modern technology for civil passenger turboprop aircraft is applicable to military transport aircraft and can lead to similar improvements, it is necessary to compare both aircraft categories with each other.

Tasks and requirements

Mission and design requirements for civil and military aircraft are different in many respects. But in the case of military transports a number of similar requirements in comparison to civil aircraft can be found. This is especially true if civil propeller transport aircraft for regional/commuter/utility missions are considered as discussed.

The tasks of both aircraft categories are basically identical, namely the transport of persons or goods from one place to another (fig.23). To a larger part the requirements are similar or even identical as for example high cruising speed, medium range and payload, good airfield capabilities, low cost operation and good mainainability (fig. 24). The military transport has to be more autonomous, flexible and robust in terms of operation and variety of goods. Civil aircraft designed for utility missions are getting very close in this respect.

However, military aircraft must be designed according to more stringent military certification rules e.g. load factors, floor strength, manoeuvrability etc. leading to higher structural weight. On the other hand the utilization of military transport aircraft in peacetime is relatively low (200-400 h/year) in comparison to civil commercial passenger airplanes (2000- 3000 h/years) having a positive effect with respect to structural weight.

General configuration

Civil and military medium transport airplanes are of very similar general configuration, especially if civil aircraft with a high wing arrangement and the main landing gear retracting into fuselage nacelles are considered (fig.25). Both types use turboprop engines. Moreover, cockpit and system design, components and material show a high degree of commonality.

There are important differences as fuselage cross-section, floor height, rear fuselage and landing gear design (fig 26).

Due to the differences in the certification rules as mentioned, military transport airplanes have to be designed according to the military requirements in order to achieve desired results in terms of performance and cost, i.e. a dedicated design is required. Derivatives of civil aircraft suffer from restrictions leading to unsatisfying military usefulness.

Applicability of civil passenger transport technology

It can be concluded that the differences between the two types of aircraft as shortly discussed are much smaller and less important than the commonalities which exist in overall configuration, technology, systems- and component design.

Therefore, the civil passenger transport technology can be used to a large extent to the military transport. The state of the art of dedicated military turboprop transports still in operation today are that of the 60's and early 70's. Therefore, the progress achieved in the civil field can be very beneficial to a new military transport.

5. APPLICATION OF CIVIL PASSENGER TRANSPORT TECHNOLOGY TO MILITARY AIRLIFT (AN EXAMPLE)

General remarks

In the following an example of an advanced medium transport is presented incorporating the most probable technological state in the year 2000. The preliminary design shown represents an extrapolation from civil transport technology as outlined in the foregoing chapters. The specific design requirements of military tranports are taken into account, too. Moreover, probable changes in tasks and operations for future medium transports are considered.

Example of an advanced medium transport aircraft

The tasks for a future transport aircraft should be oriented towards the new expected roles of the armed forces in Europe. From this point of view a medium air transport system assisting defence roles with the characteristics listed in fig. 27 seems to be very interesting.

Especially peacetime support missions after catastrophes, missions in the context of armament control (verification) and against terrorists and smuggling, UNO-support missions also for crisis management may get higher priority. Such missions will require a higher degree of mobility, flexibility and autonomy of the resp. taskforce carried to the employment area (fig. 28).

Therefore, a mobile taskforce consisting, for example, of a truck (Unimog,2 to) plus equipped container plus 4-6 troops as a selfcontained operational unit is seen as a possible design payload.

Other important requirements may be:

+ high cruise speed for quick reaction,
+ good flight manoeuvrability and take off and landing performance for excellent operational flexibility
+ medium-range capability to cover a sufficient area,
+ low operating cost comparable to those of civil aircraft.

The configuration for an advanced medium transport aircraft as an example is proposed as still conventional with high wing and two turboprop engines fitted to the wing (fig. 29). The overall design is for optimal aerodynamic drag. The fuselage is bulky with a rear loading ramp to allow the transport of 2 to trucks and contains a cabin crane system for the lifting and loading of containers and other loads (fig. 30).

Other examples of typical payloads (cross-sections are shown also in fig. 30):

+ 3 shelters (2,9 m x 2,05 m x 1,83 m),
+ 2 trucks, (UNIMOG, 2 to)
+ 4 container (88'' x 108'' x 71''),
+ 56 troops, equipped.

The operating range as illustrated in fig. 31 covers major parts of Europe, Middle East and North Africa, the latter interesting for support missions as mentioned.

The example given utilizes the following technological features (fig. 32):

+ Advanced propulsion system
+ Laminar wing technology
+ High lift flap system
+ Carbon fibre fuselage
+ Fly-by-wire technology
+ Relaxed stability
+ Advanced avionics system.

The improvements which seems to be achievable in comparison to earlier designs are given in the diagrams of fig. 33. As can be seen the lift/drag ratio of a modern design could be increased by 30 % against designs of the 60/70ies (see chap. 2). The weight break down in percentages show that the ratio: "operating weight empty/max take-off weight" will decrease only by a limited amount (7 %) due to the fact that cruise speed and relative fuselage volume (especially diameter) both have increased considerably. The max. cruise speed is 40 % higher.

Another characteristic value concerning weight represents the ratio:" operating weight empty/max. payload". This value is decreased by appr. 20 %.

Concerning a comparison of fuselage cross-sections, fig. 34 shows that a new dedicated medium transport can be designed such that it equals or even surpasses larger transport aircraft and is very superior to derivatives of civil passenger aircraft in this class, because of a more favourable floor position. The width of the cabin is comparable to a six-abreast passenger lay-out.

6. CONCLUSIONS

The performance and operating cost of modern civil passenger aircraft have improved significantly in the last 30 years due to considerable progress in aeronautical technologies and operation procedures. The military transport aircraft in operation today are of older design with operating cost not competitive with those of modern civil transport aircraft. New dedicated military transport aircraft for medium roles are not available and not under development.

Due to the high degree of commonality of civil with military transport technology a major leap seems possible for military transport aircraft,now, if civil technology are applied to a new design.

In addition, new designs could incorporate the substancial changes in tasks and requirements for future modern air tranport systems.

Because of the specific requirements for military transport aircraft dedicated designs are necessary; derivatives of civil passenger aircraft are not satisfying.

The example of an advanced medium transport aircraft is designed to possible new requirements which seem to get importance in the future. The design shows a conventional configuration using turboprop engines and incorporating foreseeable technology development. The example gives promising indications of the improvements, which are possible by applying civil transport technology.

Naturally, more detailed investigations are necessary to substanciate these statements further.

7. REFERENCES

(1) Nüßer, H.-G.
Status and future development of air transport demand
DGLR/AAAF/RAes European Propulsion Forum, Köln-Porz, April 3-5,1990

(2) Walsh,M.J.,Sellers,W.L. and Mc Ginley,C.B.
Riblet drag at flight conditions
J. Aircraft, Vol. 26, No.6; June 1989

(3) Jane's
"All the World's Aircraft"
Jane's Information Group Limited,UK

(4) Donelson,J.E.,Lewerenz,W.T.,Durbin,R.T.
UHB Demonstrator Flight Test Program Phase 2
AIAA/ASME/SAE/ASEE 25th Joint Propulsion Conference
Monterey,CA/July 10-12,1989

(5) Stock,H.W.,Haase,W.,Echtle,H.
Comparative study of calculation procedures for
viscous flow around airfoils in the transonic regime.
AGARD CP-437,1988

(6) Körner, H,, Horstmann, K.H., Köster, H., Quast, A., Redecker, G.
Laminarization of Transport Aircraft Wings
A German View
AIAA 25th Aerospace Sciences Meeting, Jan. 12.-15. 1989

(7) Brenner, L., Johst, E.
Die Zelle der Dornier 328 - erprobter Fortschritt
DGLR - Jahrestagung 1989, Hamburg, 02.-04.10.89

(8) Spintzyk,J.
Design evolution for a regional airliner
16th ICAS Congress, Jerusalem August 28-September 2,1988

8. ACKNOWLEDGEMENTS

The author thanks Dornier Luftfahrt GmbH and his colleagues for the support in preparing this paper. Special acknowledgements are given to Mr. Krojer, Mr. Heller and Mr. Moeken.

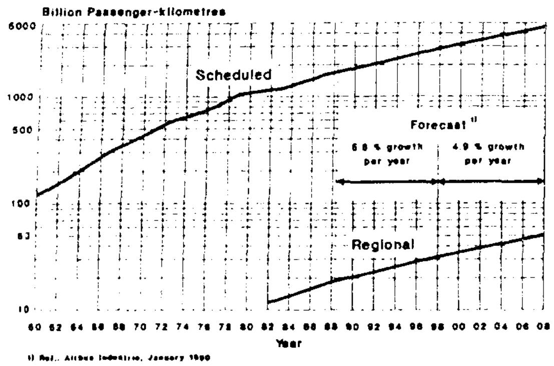


Fig. 1: World scheduled passenger transport demand

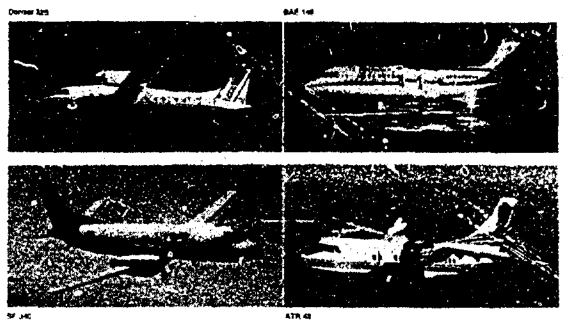


Fig. 2: Advanced civil regional aircraft (examples)

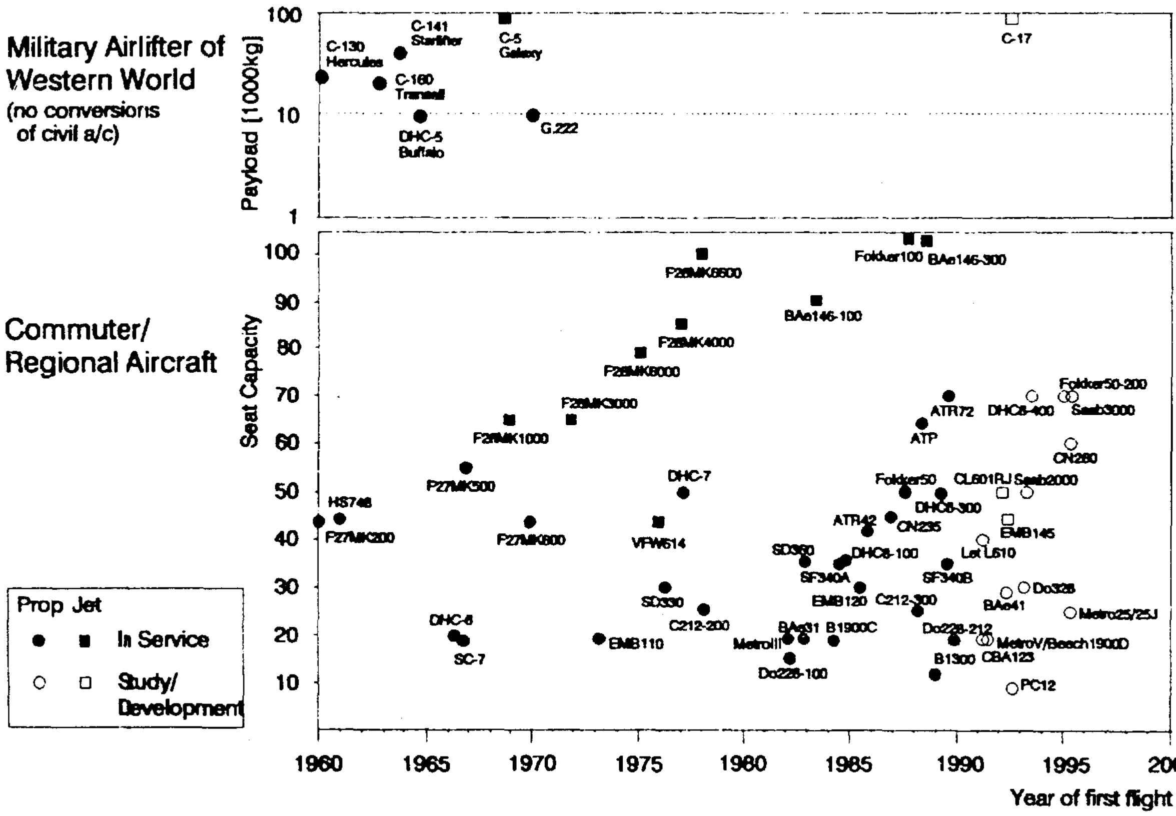


Fig. 3: Introduction of new aircraft models in airtraffic

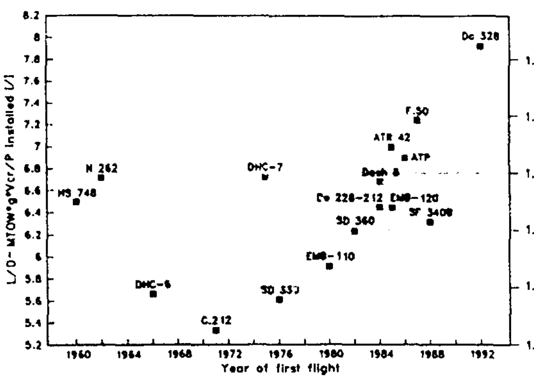


Fig. 4: Progress in civil passenger aircraft (prop) - increase of lift/drag

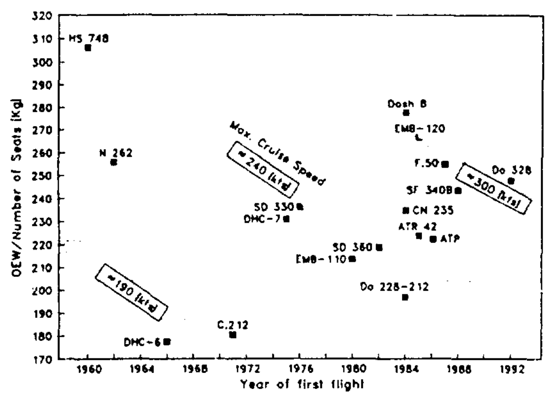


Fig. 5: Progress in civil passenger aircraft (prop) - weight reduction

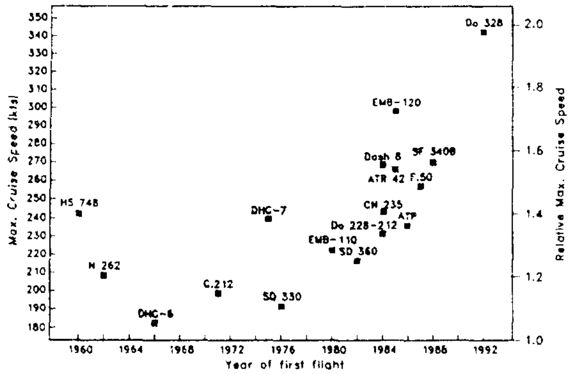


Fig. 6: Progress in civil passenger aircraft (prop) - speed increase

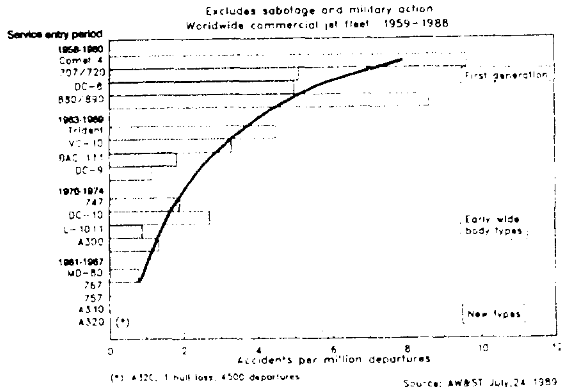


Fig. 7: Hull loss accident rates

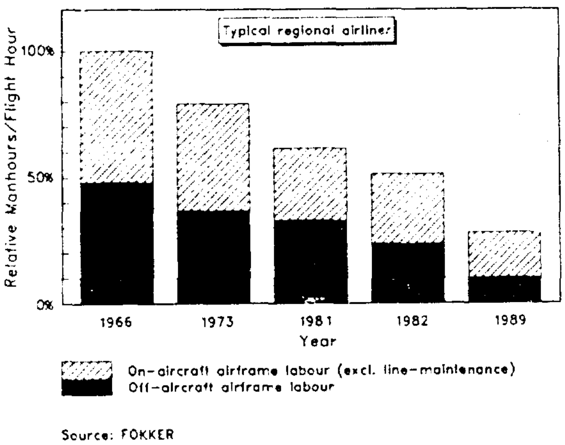


Fig. 8: Reduction of maintenance labour cost

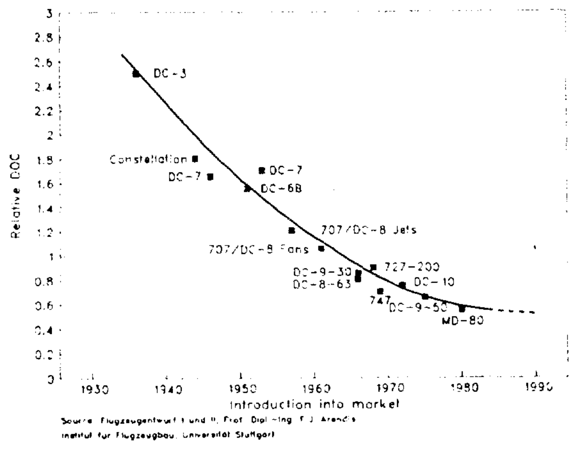


Fig. 9: Reduction of operating cost

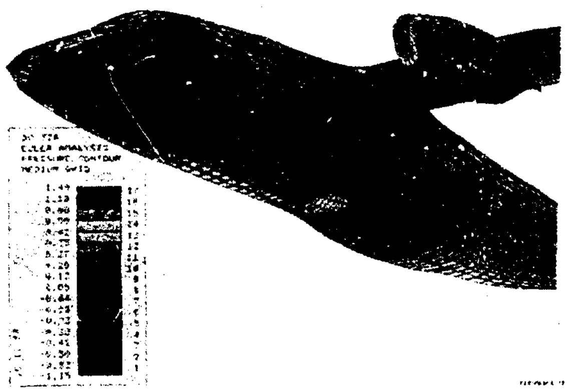


Fig. 10: Mesh for Dornier 328 wing body combination

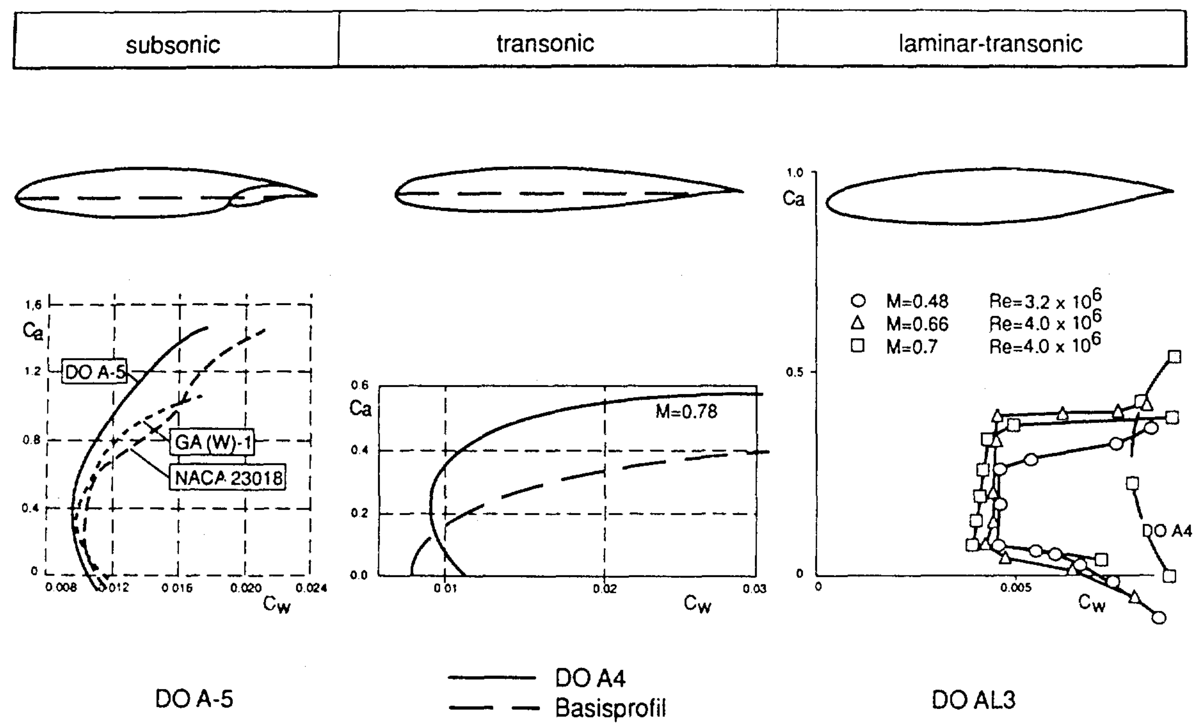


Fig. 11: Progress in wing section design

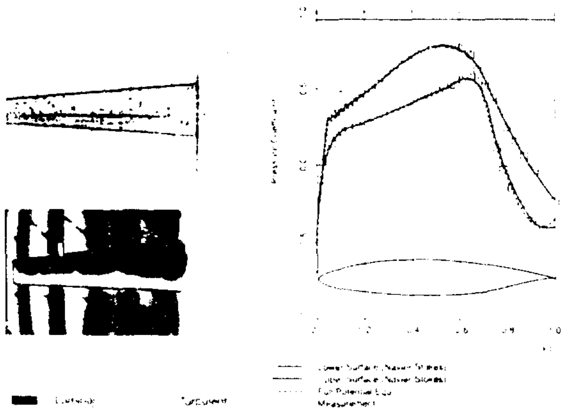


Fig. 12: Laminar wing - comparison of theory with measurement

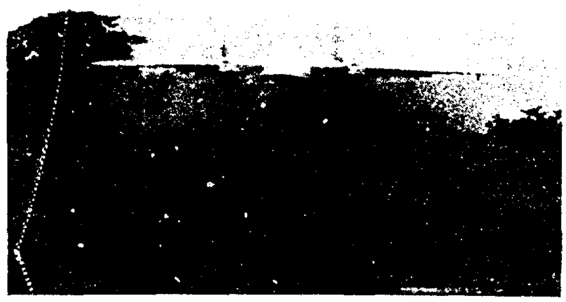


Fig. 13: Dornier 228 - rough field operation

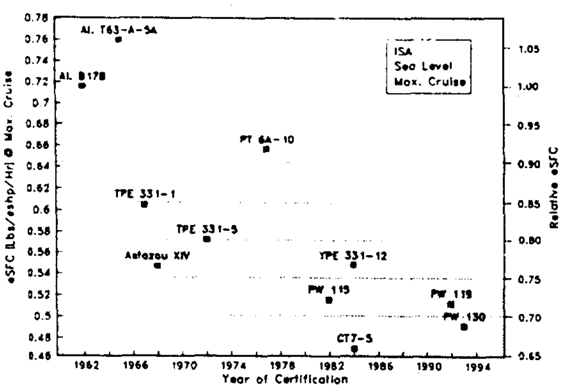


Fig. 14: Specific fuel consumption of turboprop engines

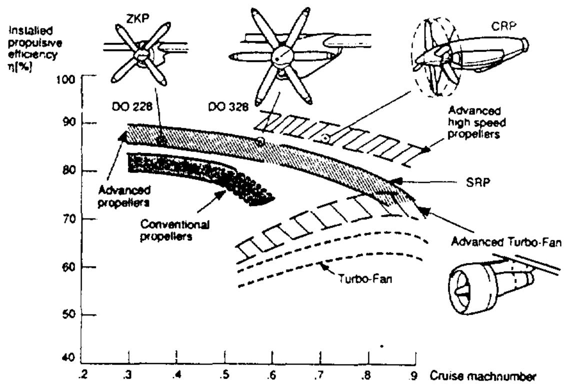


Fig. 15: Propeller development

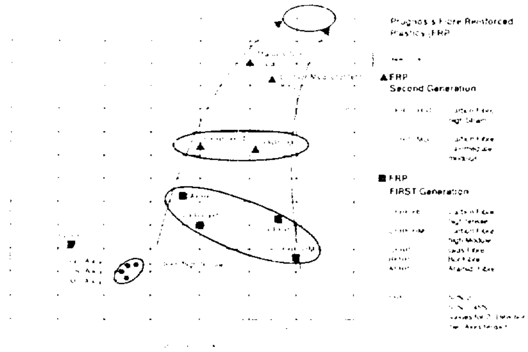


Fig. 16: Progress in material

Fig. 17: Integrally milled wing panel (Dornier 228)

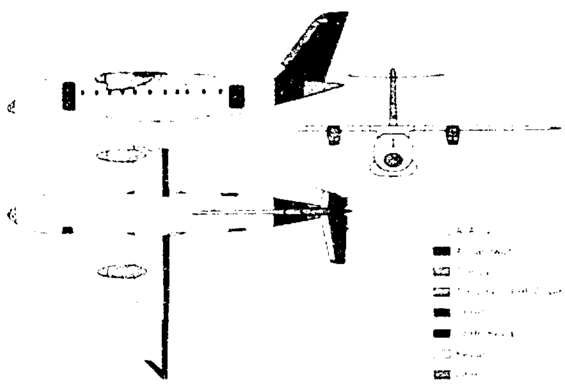


Fig. 18: Application of non metallic structures for Dornier 328

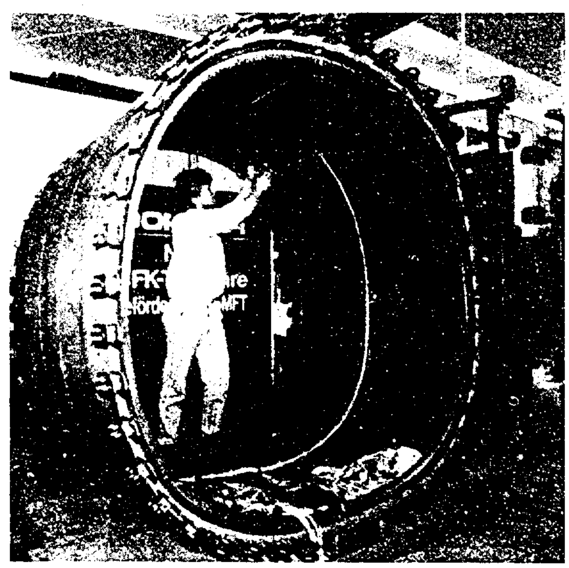


Fig. 19: CFRP - fuselage test sample

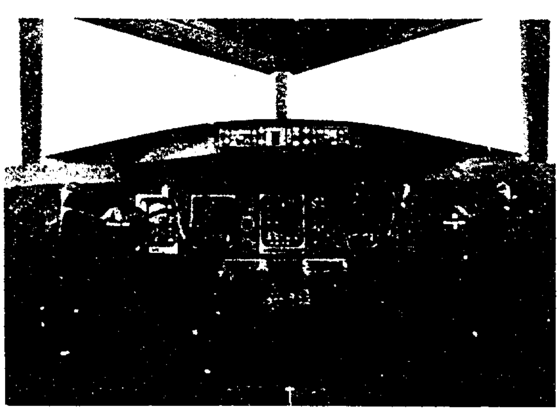


Fig. 20: Advanced cockpit design (glass cockpit Dornier 328)

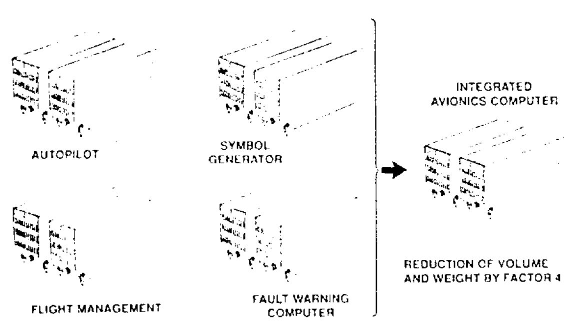


Fig. 21: Development in avionics (example)

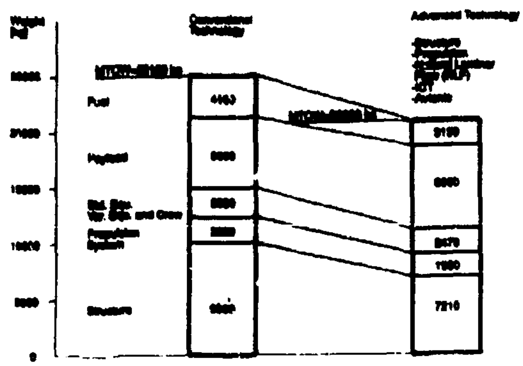


Fig. 22: Integrated effect of progress in aeronautics development for civil turboprop aircraft (weight reduction potential)

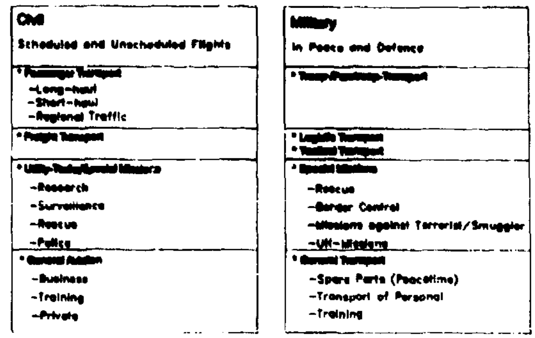


Fig. 23: Comparison of tasks

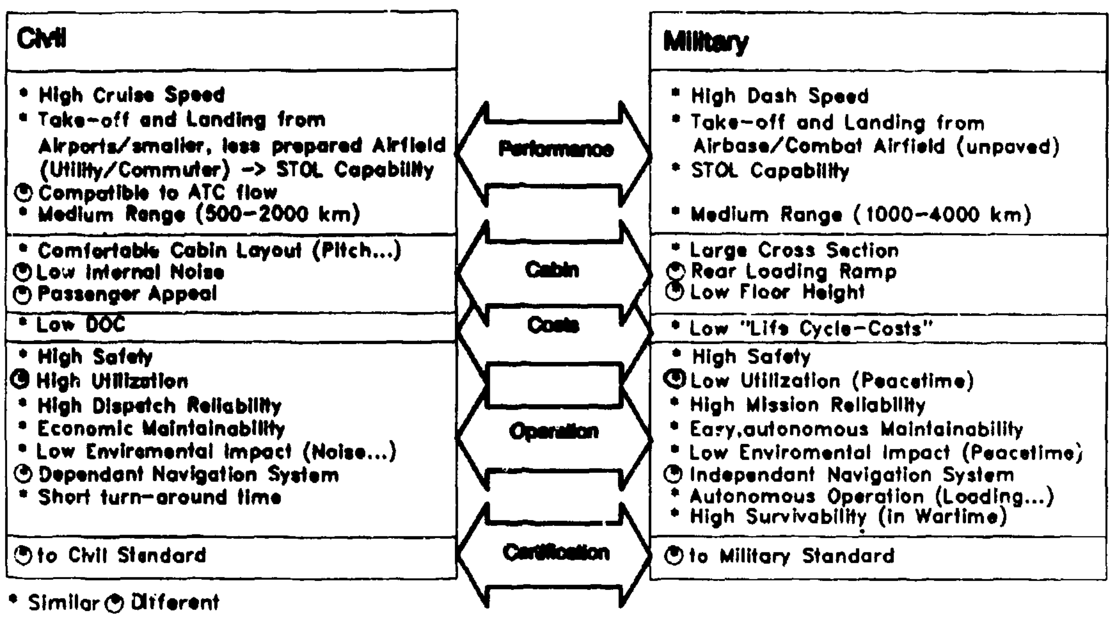


Fig. 24: Comparison of requirements

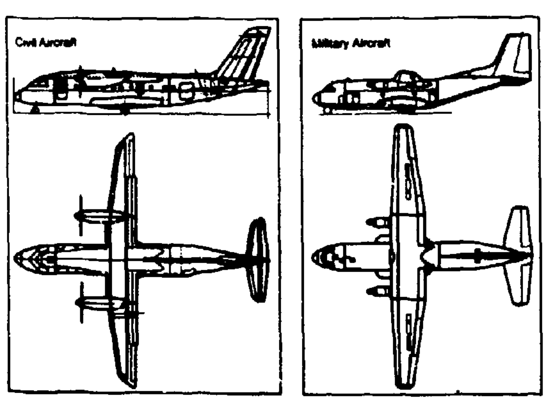


Fig. 25: Comparison of general configuration

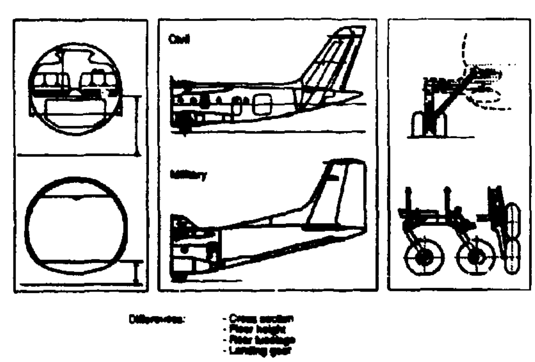


Fig. 26: Comparison of typical design features

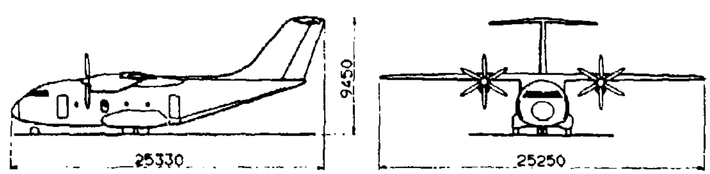
TASKS (Examples)

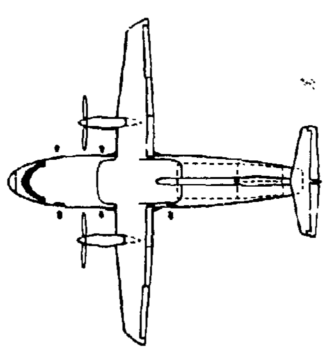
* **Transport System for Defensive Missions**
  - Quick Deployment of small Troop Units
  - Logistic Support to Focal Points
  - Casualty Transport
* **Autonomous Transport System for**
  - Disaster Operations (First Aid...)
  - Rescue Transport
  - Flying Clinic
  - Mobile Command Post
  - Verification Missions
  - UNO Missions
  - Crisis Management
* **Special Missions**
  - Maritime Patrol
  - Photo Reconnaissance
  - Electronic Intelligence
  - Pollution Control
  - Agricultural Flights
  - Mapping

REQUIREMENTS (Examples)	Values
Performance:	
* High Cruise Speed	>= 350 kts
* Range, normal	> 2000 km
* Range, extended	> 4000 km
* Payload, normal	>= 6000 kg
* Take-off Run	< 2300 ft
* Balanced Field Length	< 4000 ft
* Cruise Altitude	25000 ft
* Excellent Manoeuvreability	
* Good Rate of Climb	
Cabin/Dimensions:	
* Height	2.90 m
Length	10.00 m
Width (Floor)	3.30 m
* Low Floor Height	
* Rear Loading Ramp	
* Integrated Crane System	
Costs:	
* DOC comparable to Civil Aircraft	
Operation:	
* Transport of Mobile Unit	
– Truck (Unimog 2 t)	
– Standardized Mobile Cabin (2.9/2.05/1.83 m)	
– 4 Persons for Mobile Unit	
* Transport of 4 Container Type IGLU (2.23/2.74/1.80 m)	
* Transport of 56 fully equipped Troops	

Fig. 27: Advanced medium transport aircraft
- possible tasks/requirements -

Fig. 28: Advanced medium transport aircraft
- typical mission profile -





MAIN DATA :		
WING AREA	M²	60
MAX. TOW	KG	21 000
MAX. PAYLOAD	KG	6 000
ENGINE	SHP CLASS	4 000
TAKE-OFF RUN	FT	2 230
BFL	FT	3 600
MAX. CRUISE SPEED	KTAS	350
MAX. RANGE ...... AT MAX. CRUISE SPEED AND MAX. PAYLOAD	KM	2 000

Fig. 29: Advanced medium transport aircraft
- three side view with main data -

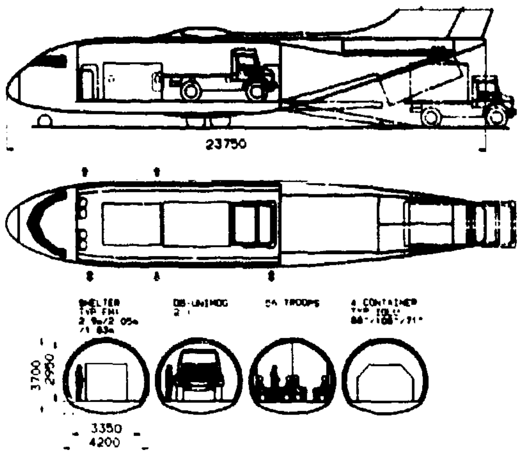


Fig. 30: Advanced medium transport aircraft
- cabin layout -

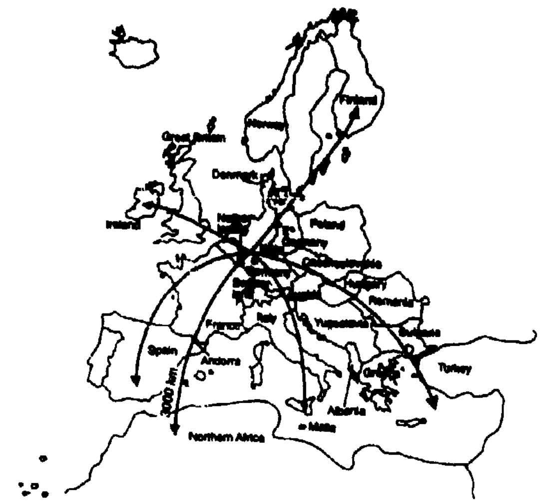


Fig. 31: Advanced medium transport aircraft
- operating range -

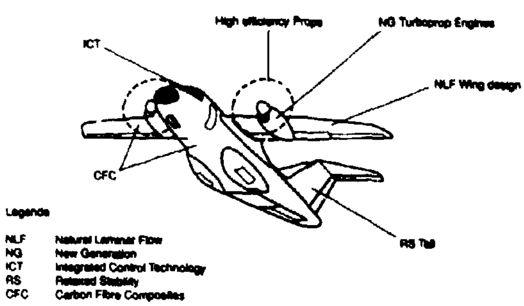


Fig. 32: Advanced medium transport aircraft
- main technology features -

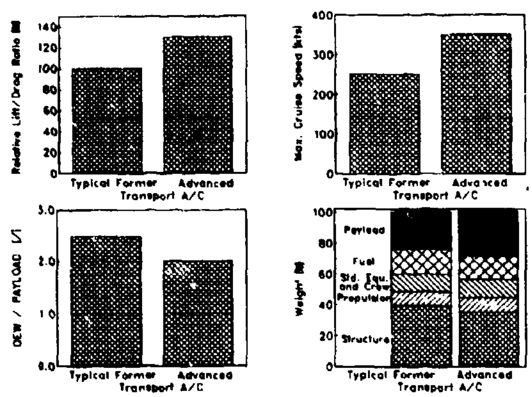
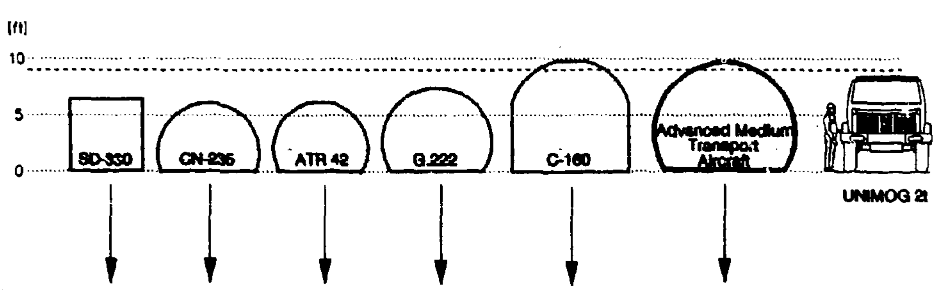


Fig. 33: Advanced medium transport aircraft
- comparisons to former generation
aircraft -



Cabin	SD-330	CN-235	ATR 42	G.222	C-160	Advanced Medium Transport Aircraft
Length [ft]	31.1 (**)	31.7	45.4	28.0	44.3	32.8
Width [ft]	6.5	8.9	8.4	8 (*)	10.3 (*)	12.8
Height [ft]	6.5	6.2	6.3	7.4	9.7	9.7
Floor Area [Sqft]	N.A.	245.7	333.7	N.A.	458.5	360.4

Remark: Cabin Length excluding Flight Deck and Ramp
(*): Floor Width
(**): Including Ramp

Fig. 34: Advanced medium transport aircraft
- comparisons of cross-sections -

PROBLEMS IN CONVERTING CIVIL AIRCRAFT TO THE MILITARY TANKER ROLE

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SUMMARY

Military tanker aircraft are being increasingly produced by the conversion of civil airliners. Civil and military aircraft are designed to different philosophies and operated in different ways, the civil operation being predictable, the military less so. This paper draws attention to these different philosophies, discusses the problems arising from typical civil aircraft conversions and suggests how future conversions can benefit from the lessons of the past.

1. INTRODUCTION

Military tanker aircraft, with their ability to act as force multipliers are becoming increasingly important even to small airforces. However with the exception of the USAF the quantities of tankers required do not normally justify production of a specialist design. This results in tankers being produced by modification of existing aircraft, initially these were derivatives of bombers, the conversion of which was regarded as a role change albeit a significant one, however with the demise of this type from most of the world's airforces the emphasis has shifted to the conversion of commercial airliners. These offer certain advantages, mainly their ready availability worldwide without political strings attached and the wide variety of sizes and types.

The UK requirement for tankers in recent years has resulted in the conversion of two civil airliners ie VC10 and TriStar. In the USA the KC-10 has been produced as a new build derivative of the DC10 and as such is not a conversion, in addition there are an increasing number of Boeing 707 conversions although most of this work is undertaken outside the USA.

The extent of the conversion depends on the type of receiver operated by the customer. If only probe equipped fighter type receivers are to be refuelled, the relatively simple task of fitting wing pods may be all that is required; however if large receivers or receptacle equipped fighters are operated then the conversion will require the addition of a centreline refuelling station or a flying boom system.

The range of Royal Airforce receivers covers all the operational types in the inventory, therefore the selected tanker must be capable of refuelling such diverse aircraft types as the Tornado, Hercules and TriStar. The scope of the UK conversions is therefore quite extensive, however since all the receiver types are probe equipped it is only necessary to fit hose reel units.

2. TANKER REQUIREMENTS

The selection of a suitable civil airliner for conversion to a tanker depends on the specific requirements of the customer:

What type of refuelling equipment is fitted to the receiver aircraft? This will dictate where the refuelling equipment can be placed eg if the receiver is equipped with a USAF type receptacle, the tanker will require a flying boom, which because of its size must be mounted under the rear fuselage.

What size are they? Fighter size receiver aircraft can be refuelled from wing pods, if probe equipped and assuming a large enough tanker, since wing/tailplane overlap will not be a problem. However if the receiver is also large then the refuelling equipment will have to be mounted on the centreline.

What quantities of fuel are to be offloaded and at what distance from base? This will determine the tanker's fuel capacity and hence weight.

What is the speed range of the receiver aircraft? Most refuelling occurs in the 250-300 kn speed range with small receivers, which is ideally suited to turbo-fan powered, swept wing aircraft. However the requirement to refuel prop driven transports or helicopters will require a tanker with compatible performance and handling characteristics.

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What is the intended area of operation? This will determine the minimum number of engines required eg operation mainly over land may permit the use of only two engines whereas long duration flight far out to sea or battle damage considerations will probably require more than two engines.

3. TANKER CONFIGURATION

If a tanker was to be designed specifically for that role, it would be possible to define its configuration from the experience gained in testing the present generation of tankers. The basic layout would comprise a high wing on which are mounted the engines, together with a high tail. The size of the aircraft and the type of refuelling equipment would be decided by the customer, however this basic configuration would allow the best flexibility for fitment.

The determination of this basic configuration is mainly intended to minimise the effects of the tanker on the receiver aircraft. This can be summarised as follows:

The high wing layout produces the maximum vertical separation between the wings of the tanker and receiver both in the refuelling position and the approach to it. This would minimise the effects of downwash from the tanker on the receiver and therefore reduce the drag rise experienced during refuelling.

The mounting of the engines on the wing would minimise the efflux effects on the receiver tail or possibly engine intakes, mounting them above the wing would be even better. On the negative side underwing engines would restrict the positioning of any wing pods. However in reality mounting the pods nearer to the tips will be required to maintain adequate lateral separation.

The high mounted tail allows maximum separation from a receiver refuelling on a wing station, furthermore it would be less effected by the "bow wave" generated by the receiver and less of a distraction to its pilot.

This configuration would allow optimum illumination of the underside of the wing from lights mounted low on the fuselage. In addition the upswept rear fuselage inherent in such a design would permit easy location of a centreline refuelling station, either hose reel or flying boom. Furthermore it would provide sufficient area to allow for the optimum positioning of night lighting and line up markings.

4. CANDIDATES FOR CONVERSION

The first and second generation of civil airliners comprised several different configurations, ranging from wing to fuselage mounted engines with low or high tails. From age and availability considerations these are becoming less likely to be eligible for tanker conversion. It is therefore necessary to look at the third generation of jet airliners ie 1970 onwards, as the most likely candidates for conversion.

This generation has virtually standardised on a low wing, low tail configuration with the engines mounted in underwing pods; the exception being the TriStar and DC10 with their third, tail mounted engine. The size of these aircraft ranging from the A320 to the Boeing 747, is sufficient to satisfy the requirements of most potential customers. High by-pass engines improve their economy and hence increase the amount of disposable fuel and furthermore the advances in modern wing design permit a wider range of speeds to be flown without resort to the use of high lift devices.

There is also the possibility of converting freighter aircraft, indeed there are a number of C130 tankers in service, however their limited fuel capacity and performance preclude them from meeting some customer requirements. There are more suitable jet powered freighters in service, however, they have only been bought in sufficient numbers to carry out the transport task. The IL-76 remains in production and could be bought new, if political considerations were resolved, but at greater cost than a second hand airliner.

Such considerations as politics, cost and availability, therefore make the third generation of jet airliners the most likely candidates for tanker conversions. What are the problems?

5. DESIGN AND CERTIFICATION PHILOSOPHIES

Civil and military aircraft are designed to different criteria and tested accordingly. The civil aircraft is intended to meet the requirements of many different customers around the world; as such the design requirements are specified not by the individual customers, since each only buys relatively small numbers, but by the certification authority for each carrier, whose responsibility is to ensure the safe carriage of the fare paying public; in reality most countries accept the certification requirements of the major manufacturer's national authorities, eg USA FAA (FAR), UK CAA (BCAR), these are now being superseded by the Joint Airworthiness Requirements (JAR).

Military aircraft are designed to the requirements of a specific customer, although consideration is given to broadening the appeal of the aircraft to improve its export potential. These requirements usually comprise a definition of the role of the aircraft and specific performance points to be met, together with a formal specification, which not only details the precise design requirements, but also specifies the manner in which the requirements will be met, eg "must comply to Mil-F-38363" (Fuel Systems).

Some examples of the differing philosophies follow:

(a) Design - The civil aircraft's basic design will be in accordance with the requirements laid down by the certification authorities of the airline purchasing the aircraft, consideration will also be given to minor changes to meet the requirements of that particular customer.

The military aircraft will be designed to a specific requirement, which will be followed up by a detailed specification, it will also have to be designed in accordance with specified criteria. Furthermore the customer will be involved in the Design Review procedure from the outset.

(b) Test objectives - The civil aircraft manufacturer will be required to demonstrate compliance with the specified airworthiness criteria, either with or without the participation of the certification authority. The test programme will be only that which is necessary to cover those aspects demanded by the authority and those guaranteed to the prospective customers by the manufacturer, because he, after all, is paying for the testing.

The military aircraft test programme will comprise, manufacturer's trials intended to establish the basic flight envelope, together with compliance with the cardinal points of the specification, or more detailed testing, depending how the contract was written. The aircraft is then handed over to the customer who will then establish the limitations within which it can be operated and its fitness for purpose. A further test programme may be required to establish reliability and maintainability, under a realistic military environment.

(c) Stability and control - The civil requirement is to demonstrate compliance with specified points defined within the airworthiness criteria.

The military requirement is to define the limits within which stability is acceptable.

(d) Performance - The commercial airline will require the aircraft to operate with a repeatable and reliable performance throughout its service life. This will probably be specified in the contract to purchase and the manufacture may incur financial penalties if not met. The aircraft will be designed accord gly.

The military requirement will be to perform at peak whilst subjected to a military envir nment, without regard to overhaul life in wartime, whilst still expecting reliability. However peacetime operation will be to a degraded performance level to take fatigue life into consideration; the analogy can be drawn as between the road going and the racing car.

(e) Engineering - Civil design requirements will be to ensure safety to the passengers at all times, together with the operators wish to keep operating costs to a minimum, thereby linking reliability with cost of operation.

The military will require the aircraft to perform reliably up to its maximum limits with a minimum of ground support equipment. As a result of experience with military aircraft in recent years greater emphasis is now being placed on reliability, maintainability and life cycle cost. Furthermore there will be additional considerations with respect to battle damage. This latter aspect tends to be random in nature, as opposed to the predictable failures which are considered in Failure Mode and Effect Analyses which are part of every aircraft design, both civil and military.

(f) Operation - The civil aircraft is designed to fly as often as possible in order to earn revenue, whereas the military aircraft is only allowed to fly within limitations. These are usually dictated by aircrew currency and the constraints of the budget, although tanker operations are also decided by the need to support other aircraft.

These different design and testing philosophies can produce problems when attempting to clear a civil aircraft for military use. The usual approach is to take the civil aircraft as the baseline and limit the assessment and testing to the changes introduced at conversion. The problem does not occur in assessing the new equipment, which can be handled in the normal way, but in assessing the basic aircraft. The problems occur in two main areas, firstly the change of use to which the aircraft has been subjected; duty cycles and loads on systems may have been increased, it may now operate in parts of the flight envelope which as an airliner it would not have been expected to. Secondly the original certification programme will have been conducted to demonstrate compliance with civil criteria which are no longer relevant to the future operation of the aircraft. Clearly it may be possible to derive some information from the original data obtained in the certification testing, however this is not always easy, often the testing would have been conducted several years before by a manufacturer who has not been contracted to undertake the conversion and therefore has no obligation to provide this data, or the data is available but requires interpretation by the individuals involved at the time, who have long since retired.

6. CONVERSION OF THE VC10 AND TRISTAR TO TANKERS

These two aircraft will be used as examples of conversions since they represent two distinct generations and two fundamentally different configurations. The UK requirement that all tankers be capable of being refuelled in flight resulted in both having a probe fitted. The changes introduced to each type can be broken down into systems as follows:

(a) Structure - The VC10 in both Standard and Super variants were converted into 3 point tankers (ie 2 wing and 1 centreline refuelling stations) as the K Mk 2 and K Mk 3 respectively. Two significant structural changes were introduced, the first was to cut away the underside of the rear fuselage in order to accommodate a Mk 17B Hose Drum Unit (HDU), since this removed a section of the pressure hull the walls and roof of the HDU bay were stressed to act as pressure bulkheads. The second change was the installation of extra fuel tanks in what was the passenger cabin, these tanks had to be stressed to withstand the 9 g crashlanding criteria.

The TriStar conversion took as its basis the -500 series aircraft, this being the long range version, contained the largest fuel capacity and was certified to operate at the highest weights of any of the TriStar family. The centreline refuelling station comprised 2 Mk 17T HDUs, the second was provided for redundancy. This requirement was driven by the distance the aircraft would operate from base which, in the event of an HDU unserviceability, would preclude the quick substitution of another tanker, should one exist, together with the lack of wing pods. The HDUs were mounted further inside the rear fuselage than in the VC10, however the exit tunnels for the hose still penetrated the pressure hull and therefore required the construction of a pressure box to contain the HDUs. Additional fuel tanks were mounted in the cargo bay, which still allowed the carriage of passengers.

(b) Fuel system - The VC10 fuel system comprised tanks 1-4 in the wings and a centre section tank containing 65000 kg of fuel, the provision of a fin tank in the super VC10 increased this to 70400 kg. The wing tanks supplied fuel to the engines and were replenished in turn from the centre tank. The fuselage tanks added at conversion, gravity fed the centre tank and increased capacity by 12000 kg. The gallery used to transfer fuel to the wing tanks was extended outboard to feed the refuelling pods and rearwards to the centreline HDU. Additional fuel pumps were installed to cover the requirement to be able to dispense fuel as well as feed the engines.

The TriStar fuel system was similarly modified increasing capacity from 96550 kg to 141225 kg, albeit also increasing maximum weight to 245000 kg. The extra fuselage tanks incorporated 8 fuel pumps of a similar type to those in the wing tanks. Both these modified systems allowed ready transfer of fuel between tanks and each also incorporated a supply pipe from the nose mounted refuelling probe.

(c) Hydraulic system - No modification to the VC10 hydraulic system was required since the refuelling equipment introduced comprised electrically or pneumatically driven pumps.

The TriStar however used hydraulic pumps to dispense fuel when high flowrates were required. Three pumps were installed, however an interlock ensured that only two could be used simultaneously. At times of high demand eg undercarriage retraction or high rate refuelling, when the capacity of the engine driven pumps was exceeded, air turbine powered pumps supplied by engine bleed air, were used to supplement the normal sources.

(d) Electrical system - The addition of extra fuel pumps, together with the refuelling hose rewind motor (Mk 17 HDU only) were driven by the aircraft electrial system, in both aircraft.

(e) Powerplants - No change in the engines was required for the tanker role.

(f) Undercarriage and tyres - The conversion to the tanker required no design changes as such, other than those associated with an increase in maximum weight.

(g) Avionics - The change from civil to military use required the fitment of military avionics eg UHF, Tacan, OMEGA, and eventually RWR and JTIDS. In addition the ability to see behind and to the side of the tanker resulted in the fitment of a closed circuit television monitored by the Flight Engineer.

7. PROBLEMS ASSOCIATED WITH THE CONVERSIONS

(a) Airframe - The problems occurred in two main areas: firstly the installation of additional fuel tanks; the fact that the fuel was contained in its own discrete tanks located within the fuselage meant that the static and dynamic loads from this mass of fuel, was reacted at the fuselage mountings. This resulted in the introduction of "point" loads to the structure and required localised strengthening, in the form of doubler or even tripler plates. In the civil role the load, whether passengers or cargo, is evenly distributed within the fuselage. The second problem was experienced with the TriStar, where differences with build were found between nominally identical airframes. This made it difficult to produce a jig for the airframe modifications which could be used on all aircraft.

(b) Fuel system - The ability to move fuel at high rates and hence velocity during refuelling, resulted in the generation of high surge pressures. This was true whether the aircraft was acting as a receiver or tanker. Most aircraft have their fuel systems divided into a series of discrete tanks, which individually can only accept relatively low fuel flows into them, this normally results in only small step decrements in flow as the tanks fill to full, thereby minimising surge pressures. The TriStar however, is an exception to this, which is probably also true for other aircraft similar in size or larger, where high flow rates are required into each tank to keep ground refuelling time acceptable. The problem could have been overcome in any of three ways: (a) strengthen the fuel pipes to accept the surge pressures, (b) use slow closing refuelling valves, this may not work because at some point during the closing sequence the flow through the valve will effectively "choke" and cease even though the valve is not physically closed, (c) restrict the flow prior to tank shut off, this was only necessary when the final tank was filling, because otherwise there would always be flow into another tank and hence an "escape route" to dissipate any surge. This could be accomplished by the tanker reducing flow or the receiver dropping back thereby closing the tanker refuel valve and tripping off the high pressure refuelling pumps, before restoring flow and topping off on the boost pumps. The latter solution was favoured since it involved no modifications and hence incurred no extra cost.

The carriage of fuel within the fuselage pressure shell, together with the requirement to vent the tanks to atmosphere, meant that the tanks had to be able to withstand the cabin differential pressure. This resulted in the use of bladder tanks contained within their own pressure shell. The resulting method of construction incurred a considerable maintenance penalty.

(c) Hydraulic system - Using the hydraulic system to drive the refuelling pumps on the TriStar, placed an increased demand on the engine driven pumps. This could result in the supplementary air turbine driven pumps being used. The maintenance policy for these units initially assumed a safe design life, which in airline service, where the units experience a predictable number of cycles, the inspection time could be anticipated. However in military use, where it is not possible to predict the number of cycles, a different maintenance policy would have to be introduced.

(d) Electrical system - The addition of extra fuel pumps, together with the refuelling hose rewind motor (Mk 17 HDU only) resulted in increased loads on the electrical system. Whilst the overall load was not significantly increased, the type of load was changed; the principal source of electrical loads on the civil airliner were the galleys, these produced mainly resistive loads, whereas the tanker systems required electric motors, either to drive fuel pumps or rewind hoses, these loads were reactive in nature with varying power factors.

(e) Powerplant - Civil operation of the engines results in predictable duty cycles and smooth handling, which dictates the overhaul life. In the tanker role, for receiver aircraft considerations it was sometimes necessary to operate the TriStar with the centre engine at idle. This not only increased the oil consumption, due to the lower air pressure on the seals, but also degraded the performance of engine driven systems eg hydraulic pumps and anti icing bleed air. Operating the tanker as a receiver, which required continual throttle movement, in order to change or maintain position astern the tanker, resulted in a completely different duty cycle. Furthermore operating the engines in the airflow astern the tanker, at the increased power settings necessary, could produce other problems. In the case of the VC10 pop surges were experienced, in the TriStar, large increases in vibration and TGT could occur. These effects will be detrimental to the overhaul life of the engine.

(f) Undercarriage and tyres - The VC10 tanker conversion did not increase the weight from that previously certificated, therefore no modification to the undercarriage was required. The TriStar however increased the maximum weight from 228000 kg to 245000 kg, whilst this remained within the structural limits for the undercarriage it did require an increase in tyre pressure, furthermore the nose tyres were replaced by ones of a higher ply rating. Due to the lack of information on the effect of increased tyre loads on acceptable taxy distances, tests were conducted to establish tyre temperatures, this resulted in operating limits being applie. One further difference between civil and military use, is the requirement for the aircraft to remain fully loaded on standby for prolonged periods and then become operational without recourse to additional maintenance. This heavyweight standby could be detrimental to the undercarriage, in that the oleos could lose pressure, or where not fitted with separator pistons the gas could dissolve in the oil, thereby reducing oleo extension; the tyres will also tend to form flat spots, requiring periodic rotation.

(g) Avionics - Installation of military avionics caused problems. The UHF radios introduced to the TriStar were not compatible with the commercial headsets in use and required a change of headset, this was also beneficial in that the better acoustic protection provided, helped counter the increased noise levels generated by the addition of the refuelling above the flightdeck. Positioning of the additional avionics to achieve optimum performance on the TriStar resulted in excessive lengths of feeder cable, which had a detrimental effect on signal strength. The closed circuit television camera was positioned below the rear fuselage to provide the necessary field of view, with the monitor located on the flight deck, therefore requiring long feeder cables. The result was considerable electrical interference; the cables therefore had to be screened and carefully routed to avoid such things as the cabin fluorescent lighting.

8. WHAT ARE THE LESSONS FOR THE FUTURE?

All aircraft design is a compromise, the tanker, which is usually a conversion from an aircraft optimised for another purpose, is therefore more of a compromise than most.

Do not assume that any civil aircraft of the right size, or that is readily available, will make an acceptable tanker. The trend to two crew operation may not be compatible with the crew requirements of a tanker. The lack of a dedicated navigator on the TriStar increased the workload of the pilots. In airline service, operating known and predictable routes, using advanced flight navigation systems this is acceptable. Whereas in the tanker role, in what may be a constantly changing situation, whilst trying to control a formation and fly the aircraft, this can become unacceptable. The loss of the flight engineer from the latest generation of airliners, will cause a major problem for future conversions. Since during refuelling operations it is the flight engineer who undertakes the task of transferring the fuel, maintaining the centre of gravity, monitoring the systems and keeping an eye on the aircraft astern. To transfer these tasks to the pilots will not only give them an excessive workload, but also, considering the confines of the flightdeck, may require a considerable redesign to enable them to do it.

Select the worst receiver type and fly it in a representative refuelling position behind the candidate tanker, to see if there are any insurmountable problems.

If possible in a wind tunnel, check how the refuelling equipment behaves behind the tanker.

Study the aircraft systems to determine whether their loads and duty cycles have been effected by the change of role.

Consider the design and certification philosophy of the original aircraft and establish whether it is compatible with its new role. Extra trials to cover areas not required for civil certification, will prove both time consuming and expensive.

Consider before selecting the lowest bidder, the experience acquired by the original manufacturer and the availability of design and certification data on the type.

Last but not least review the requirements and place them in an order of priority eg essential, highly desirable and desirable, since this will have a considerable influence on inevitable compromises that will have to be made in selection, design, conversion and testing.

C 160-TRANSALL LIFE TIME EXTENSION

by

AD-P006 259

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1. Introduction to the C 160-Transall programme

The C 160-Transall was initiated by the French-German Transporter Allianz Consortium in the late 50ies. The aircraft was developed and produced to specifications of the French and German Airforces. ~~The main characteristics of the aircraft are shown in figure 1 to 4.~~ The aircraft was built in a partnership ~~according to fig. 5~~ with VFW-Fokker later merging into the transport division of MBB, which recently was set up on its own as Deutsche Airbus GmbH (DA) in the course of the MBB and Daimler Benz merger.

DA and Aérospatiale are again partners in the EUROFLAG consortium (European Future Large Aircraft Group) which was constituted with British Aerospace, Airitalia and Casa as further partners to manage the future large aircraft programme, the envisaged C 130 and C 160 successor. (25) * Transport aircraft, * Life expectancy (Service Life). *

The chronology of the main Transall events is shown in fig. 6. 160 aircraft were built in a first series and went into operation with German Airforce (90), French Airforce (50), and Turkish Airforce (20). In a second series initiated by the French government another 35 aircraft were produced, 6 for the Indonesian Pelita Company and 29 air-to-air refuellable versions for the French Airforce with 10 tankers and 6 versions for special military intelligence missions included (see fig. 7). The product support of the German, Turkish and Indonesian aircraft has been carried out under German leadership in close cooperation between government authorities and industries. Therefore the following remarks refer to these aircraft only.

112 of originally 116 German, Turkish and Indonesian aircraft are still in operation, most of them being near to the end of their certified life, which originally was calculated to 5,000 flights of about 2 hours each within 20 to 25 years. The average age of the aircraft is between 4,000 and 5,000 flights of about 1.2 hours each now. The structural life time reserve, the relatively good conditions of the aircraft and budget problems caused the German MoD authorities to extend the C 160 operation by another 20 years with a total of 12,000 flights of about 1.22 hours each until about 2010. This decision was taken, well aware of increasing difficulties to maintain product support for systems and equipment of 1960-technology standard, some of which will have to be replaced.

The French MoD had already decided independently in a similar way at an earlier time.

2. Procedure for life time extension

The measures for life time extension have to cover

- o aircraft structure and systems fatigue, wear and corrosion,
- o systems maintainability and supportability
- o adaptations to new operational requirements and modern standards (where really required),
- o maintenance and update of programme data basis, documentation, software, procedures, etc.

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The following steps have been decided:

I. Regarding Structure:

1 Inspect the structure of exemplary aircraft paying special attention to heavily stressed components in order to find out kind and degree of damages and the priority of measures to be taken.

2 Define and carry out structural ground tests with the still existing static/dynamic test aircraft taking into account stress cycles derived from actual operations and artificially introducing initial damaging (i. e. cracks) at particularly endangered places in order to find out damage behaviour and crack propagation.

3 Equip one aircraft with strain gauges and MSR (mechanical strain recorder) to determine load transfer functions of critical aircraft components.

4 Define and carry out an inspection programme for 3 exemplary aircraft especially regarding those parts of the aircraft which have not been subject to periodic maintenance procedures such as HPO (Hourly Post Inspection, after prefixed flight hour cycles), PE (Periodical Inspection, 36 month cycle), DI (Depot Inspection) to assess

corrosion,
wear,
fatigue,
friction, backlash of movable parts,
surface protection.

5 Analyse results from 1 to 4 and define measures

to eliminate deficiencies,
to take preventive actions

and assess viability and efficiency of these measures by tests.

6 Derive actual stress cycles from operational and test experience and apply these stress cycles to the aircraft structure with the modifications according to 5; calculate extended life time of the modified aircraft. If the result does not satisfy the requirement of 12,000 h life time, define measures for those parts of the structure which do not satisfy the requirement.

7 Carry out all measures defined under 5 on all series aircraft.

II. Regarding Systems

1 Analyse systems with respect to

- o maintenance cost increase of existing systems during the next two decades compared with replacement by new systems,
- o system corrosion and wear,
- o systems adaptations required by functional and operational reasons,
- o systems alternatives.

2 Define measures for systems repair.

2. Define measures for systems repair.

3. Decide system modifications and replacements and initiate equipment procurement, integration, test and certification with one exemplary aircraft.

4. Carry out all modifications on all series aircraft

3. Measures referring to structure

3.1 Structure inspection and test results

The selected spots of heavily stressed components predominantly referred to special rivet holes. Damages could be put down to manufacturing deficiencies instead of aging effects.

The wing proved to be the weakest structural part, i. e. best designed to life, especially

- o the station 1560 (near wing/fuselage connection) does not withstand more than about 5100 flights,
- o two stations at the outer wing are endangered as well,
- o reinforcements at station 1560 cause increased stress at stations 1910.

Different rivet hole expansion methods have been analysed and tested with test specimens specially prepared to conditions derived from C 160 manufacturing procedures and aging peculiarities. The achievable degree of strainhardening and associated life time extension could be demonstrated to be more than a factor of two in each case.

A thorough inspection programme covering more than 1,000 examination items in those parts of the aircraft which had not been subject to periodical inspections (HPO, PE, DI) was carried out with 3 aircraft concerning structure and systems installations (equipment itself excluded) as shown in the following table:

Airframe	40 %
Flight control system	25 %
Undercarriage	5 %
Engine-related installations	5 %
Electrical System	5 %
Instruments	
Environmental Control	
Hydraulics	20 %
Lights	
Fuel system	
Fire warning and extinguishing systems	

The areas of increased corrosion as found during the inspection programme can be seen from fig. 8

3.2 Resulting measures

The measures derived from the above results are listed below:

- Reinforcement and strainhardening of important parts of the wing structure (see fig. 9);

- a number of immediate repairs to prevent further damage progress such as

  - o exchange/replacement of different mounts and joints,
  - o elimination of corrosion and improvement of surface protection in hot air areas and battery compartment,
  - o cavity sealing;

- other repairs to be carried out at next depot inspection mainly concerning corrosion elimination and prevention;

- some minor design changes;

- total replacement of the electric wiring incl. connections;

- adaptation of maintenance and inspection programmes for the future,

- determination of remaining structure life by

  - o evaluation of strain gauge, MSR and other test results,
  - o adaptation of stress cycles,
  - o analysis and certification of fatigue strength of the modified aircraft with accumulated damaging.

4. Systems modifications and replacements

4.1 Navigation system

Due to new tactical requirements and a deteriorating product support situation, the navigation system is being replaced by a modern but proven technology system. This means the removal of the main navigation system components such as

the analogue navigation computer,
the Doppler system,
the gyro reference,
the LORAN C.

At the same time the control units for VHF-Comm./Nav., TACAN and HF will be removed and replaced by a central control concept.

The new system for which Rockwell Collins was selected as main supplier is described by its block diagram (fig. 10), its main features are

- autonomous navigation capability by high precision Laser inertial Navigation System (LINS),

- navigation update by GPS to reduce long-term navigation errors to less than 500 m,

- digital control and display units for centralised navigation and radio management,

- improved display capability by electronic horizontal situation indication,

- enhanced failure survival capability by using the autopilot AHRS as heading sensor back-up,

- improved operational capability by introduction of mission data entry and computer aid for map display, cargo release, take off and landing data etc.

- improved system integrity, reliability, testability and growth potential (MLS, NIS etc.) by application of MIL-Std. 1553 B.

The new navigation system results in major changes to the cockpit panels lay-out, especially referring to the central pedestal (see Fig. 11). The navigator place is dedicated to special tactical mission tasks and may be deleted for normal ICAO flights.

4.2 Autopilot/Flight Director System

The increase of costs for product support and of reaction times in cases of complaints and the decreasing reliability of components forced the aircraft owner to replace the initial autopilot system by a modern standard system. The new system is described by the block diagram (fig. 11). The main features of this system for which Honeywell Sperry are selected as main supplier, are

- redundancy by duplicating autopilot/flight director computers (one active, the other in stand-by) and making additional use of navigation sensor sources,

- an improved and extended mode concept,

- incre‸ ‸d sensor reference precision and actuators with increased power and dyna‸ ‸s both resulting in improved flying qualities,

- reduced failure monitoring thresholds resulting in improved failure behaviour,

- improved maintainability and reliability resulting in reduced costs and improved availability.

4.3 Wiring system

Most of the wiring in the cockpit and front part of the fuselage has to be redesigned as a consequence of the navigation and autopilot systems replacements. Taking into account the ‸sion‸ ditions of all wirings and connectors especially in the non-pressurised parts of the aircraft and the adverse effects of opening up and re-arranging aged wiring bundles, it has been decided to remove and replace the whole electric wiring system including all connectors with the exception of the high-power distribution wires.

4.4 Exchange of existing a‸ ‸troduction of new avionic subsystems

To ensure maintainability at reasonable costs for the future the following subsystems have been replaced by modern standard subsystems

- Weather radar transmitter/receiver,
- Radio altimeter including antenna positioning,
- HF-transmitter/receiver subsystem.

Due to operational requirements, a SELCAL- and a Data Telecommunication capability has been integrated.

5. Programme procedures, documentation, data basis etc.

With the aircraft life time of more than 40 years, problems with respect to programme handling arise and have to be solved. This may be demonstrated by the following examples:

- The original aircraft development did not make use of any computer aid. So design, manufacturing, analysis, documentation etc. were done manually. In the mean time, computer aid has become general standard and engineers have lost their skills in manual procedures. So a reasonable degree of change to computer aid has to be provided (and paid for) to ensure product support in a responsive and correct manner.

- Drawings, part lists, certification reports, engineering documentation etc. are subject to a natural aging process with respect to

  physical constitution (readability, reproduceability),
  obsolete contents (e. g. material not longer in use or deliverable).

  Hence increased effort for restauration and continuous maintenance has to be expended.

- Especially regarding engineering background, the personal experience of those who developed, tested, certified and maintained the aircraft and its components is extremely helpful for any later trouble shooting. After 30 years none of those who gained the know-how in the early phases of the programme is still available. So some sort of know-how safeguarding and transfer has to be organised.

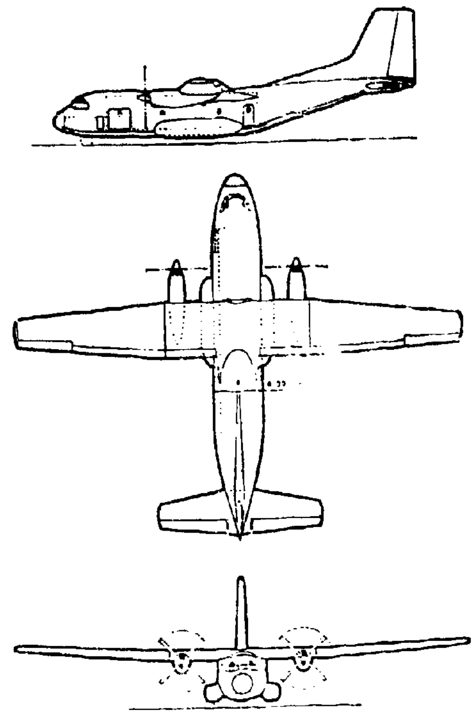
Problems of this kind have been permanently discussed between users, certification authorities, government maintenance responsables, industry, etc. with the result of systematic analysis and implementation of all required actions. This is still in progress.

6. Time schedule

Is is obvious that only certain aspects of life time extension require immediate action or strict time discipline. So the major portion of the actions have been planned and implemented in accordance to budget availabilies. This leads to a rather stretched time schedule shown in fig. 13.

The work progress is in due compliance with this time schedule.

FIG.1 GENERAL CHARACTERISTICS



MAIN DIMENSIONS

Wing Span	40 00 m	131 ft 3 in
Overall Length	32 40 m	106 ft 4 in
Overall Height	11 65 m	38 ft 3 in
Wheel Track	5 10 m	16 ft 9 in
Wheelbase	10 48 m	34 ft 6 in
Propeller diameter	5 50 m	18 ft 0 in

AREAS AND LOADINGS

Wing	160 m²	1 722 sq ft
Horizontal Tail	43 80 m²	471 sq ft
Vertical Tail	36 00 m²	387 sq ft
Wing Loading	318 75 kg m²	65 3 lb sq ft
Power Loading	4 18 kg e h p	9 2 lb ehp

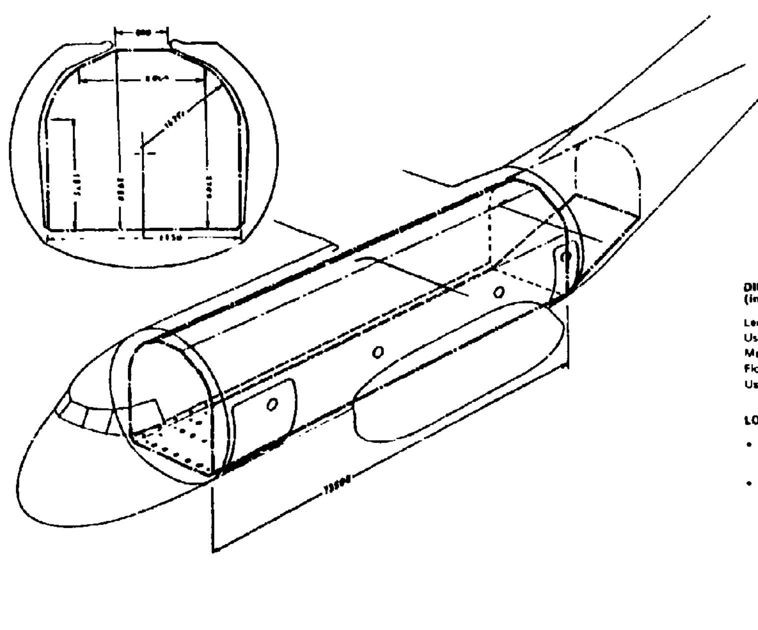
WEIGHTS

Max take off weight	51.000 kg	112 435 lb
Max landing weight	47 000 kg	103 620 lb
Min operating weight empty	28 000 kg	61 730 lb
Max zero fuel weight	45 000 kg	99 230 lb
Maximum payload	17 000 kg	37 500 lb
Fuel capacity		
Without center wing fuel tanks	19 050 lit	5 020 US Gal
With center wing fuel tanks	28 050 lit	7 410 US Gal

ENGINES

Two ROLLS ROYCE SNECMA Tyne Mk 22 developing a take off power at sea level of 2 × 6100 e h p at ISA and 2 × 5950 e h p at ISA + 22 °C with water methanol injection

FIG.2 DIMENSIONS OF HOLD



DIMENSIONS OF HOLD (including ramp)

Length	17 21 m	56 ft 6 in
Useful width	3 15 m	10 ft 4 in
Max useful height	2 98 m	9 ft 9 in
Floor area	54 25 m²	583 9 sq ft
Usable volume	140 m³	4,940 cu ft

LOADING ACCESSIBILITY

- Main rear loading ramp and aft cargo door (full cross section)
- Floor lowering capability to ease loading

FIG.3 PAYLOAD/RANGE

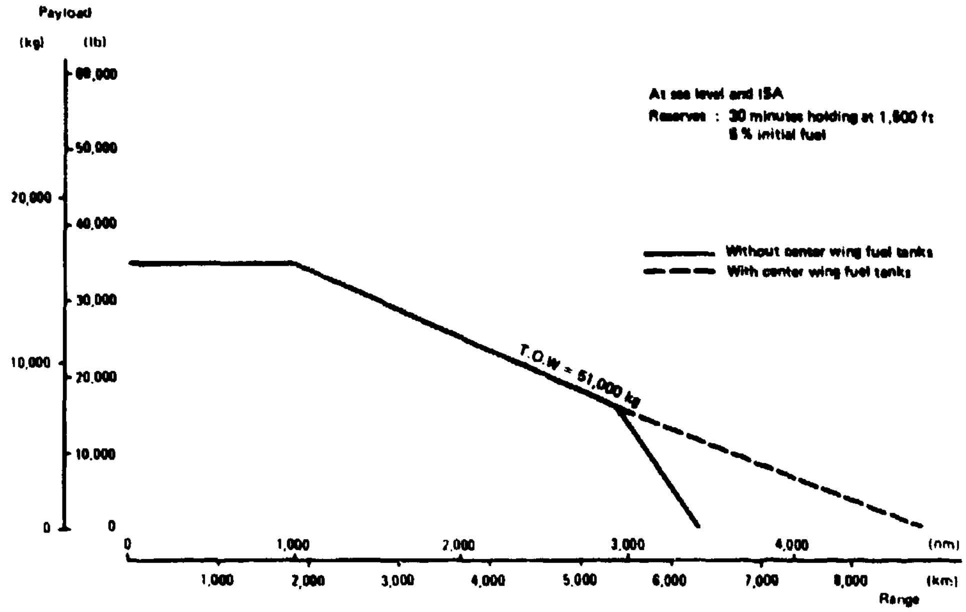


FIG.4 FLIGHT ENVELOPE

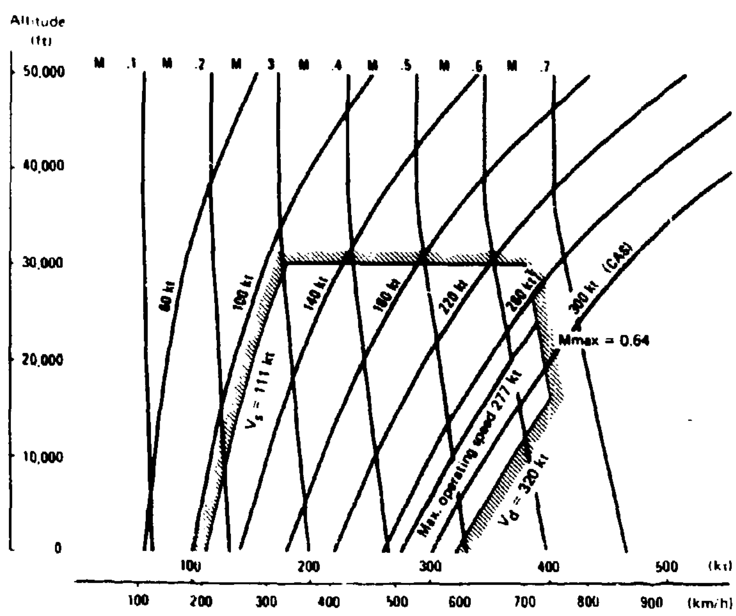
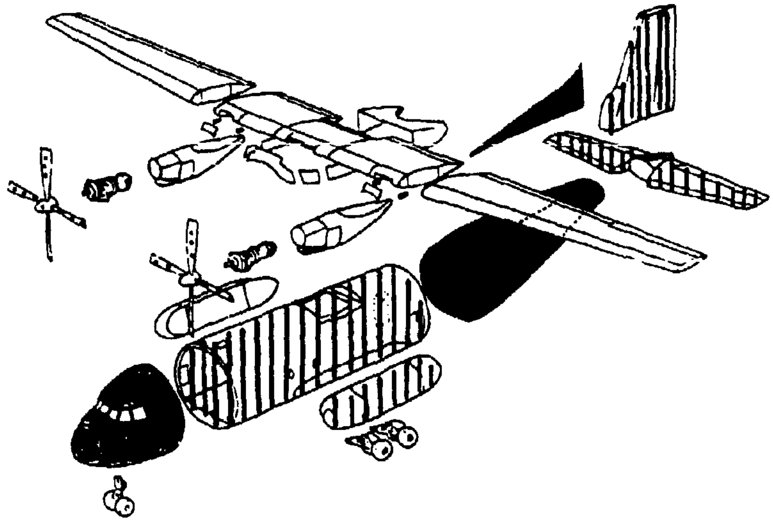


FIG.5 PRODUCTION BREAKDOWN



	Company	Location
(black)	MBB	Hamburg
(vertical stripes)	VFW-FOKKER	Bremen
(white)	AEROSPATIALE	Toulouse Nantes Méaulte
(cross-hatched)	MESSIER-HISPANO-BUGATTI LIEBHERR-AERO-TECHNIK	Montrouge (Paris) Lindenberg
(dark stippled)	SNECMA / ROLLS-ROYCE	Châtellerault
(dots)	RATIER-FOREST	Figeac

FIG.6 PROGRAMME TIME SCHEDULE C160

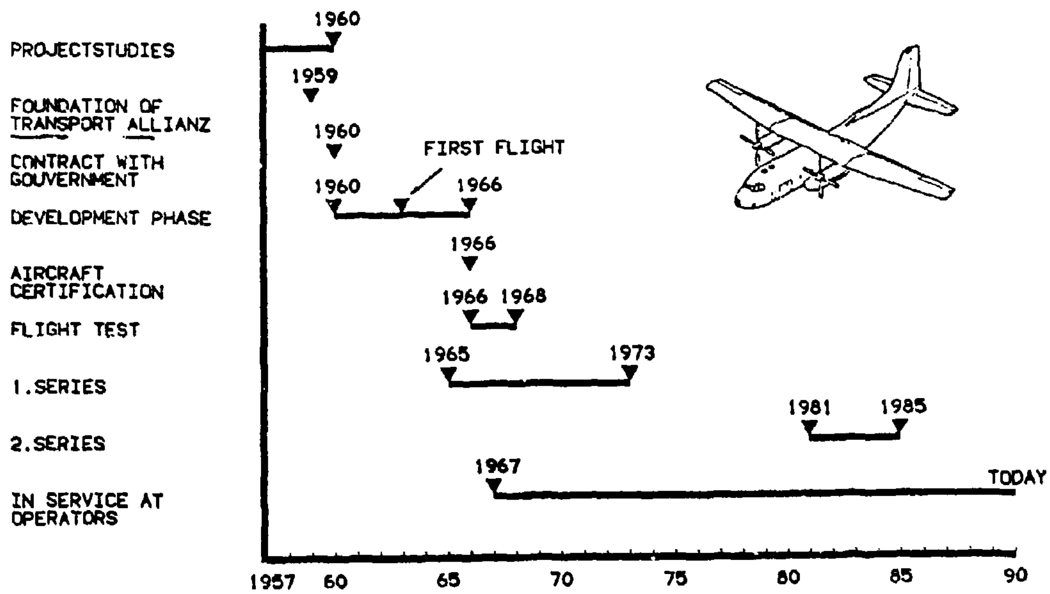


FIG.7 C160 TRANSALL DELIVERIES

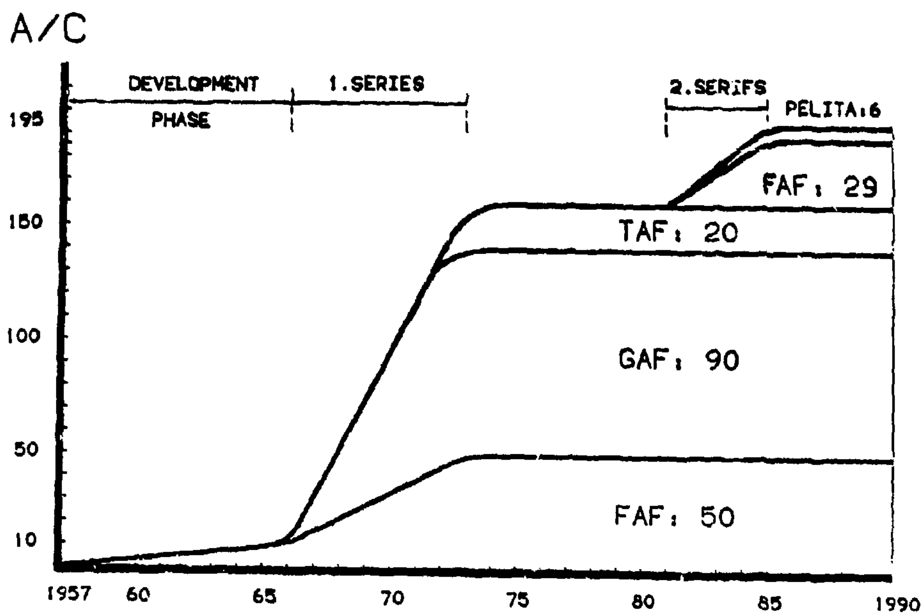
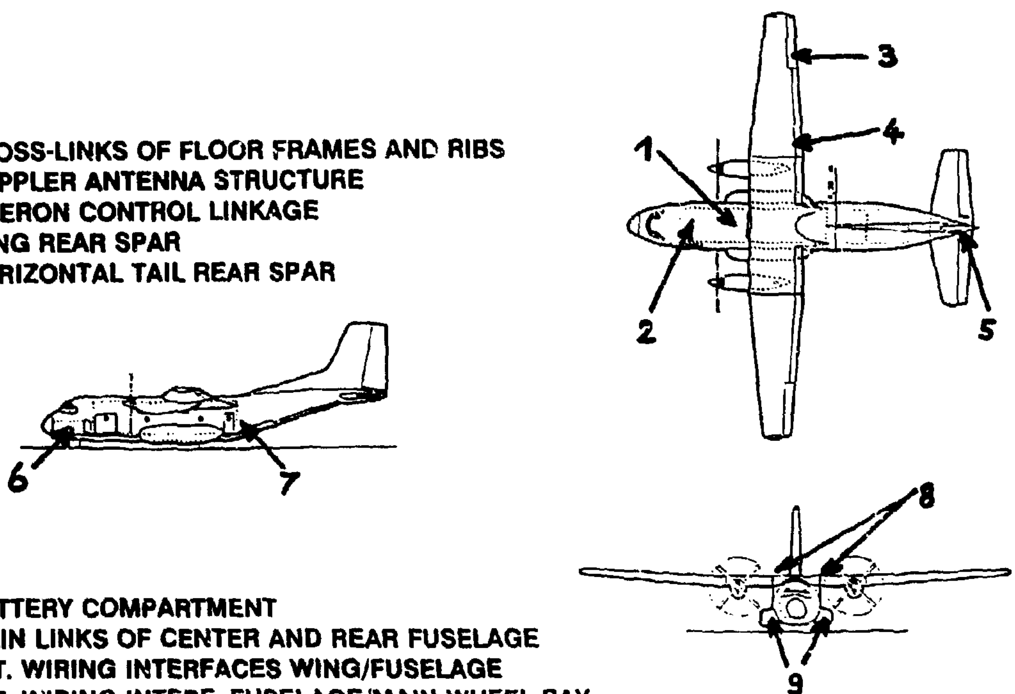


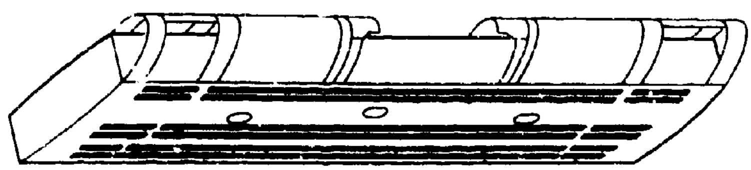
FIG.8 C160 TRANSALL MAIN POINTS OF CORROSION

1 CROSS-LINKS OF FLOOR FRAMES AND RIBS
2 DOPPLER ANTENNA STRUCTURE
3 AILERON CONTROL LINKAGE
4 WING REAR SPAR
5 HORIZONTAL TAIL REAR SPAR



6 BATTERY COMPARTMENT
7 MAIN LINKS OF CENTER AND REAR FUSELAGE
8 ELT. WIRING INTERFACES WING/FUSELAGE
9 ELT. WIRING INTERF. FUSELAGE/MAIN WHEEL BAY

FIG.9a WING REINFORCEMENTS



6 PLATES (6 mm x 65 mm) ALONG
THE CENTRAL WING (BOTTOM SIDE)

FIG.9b WING REINFORCEMENTS

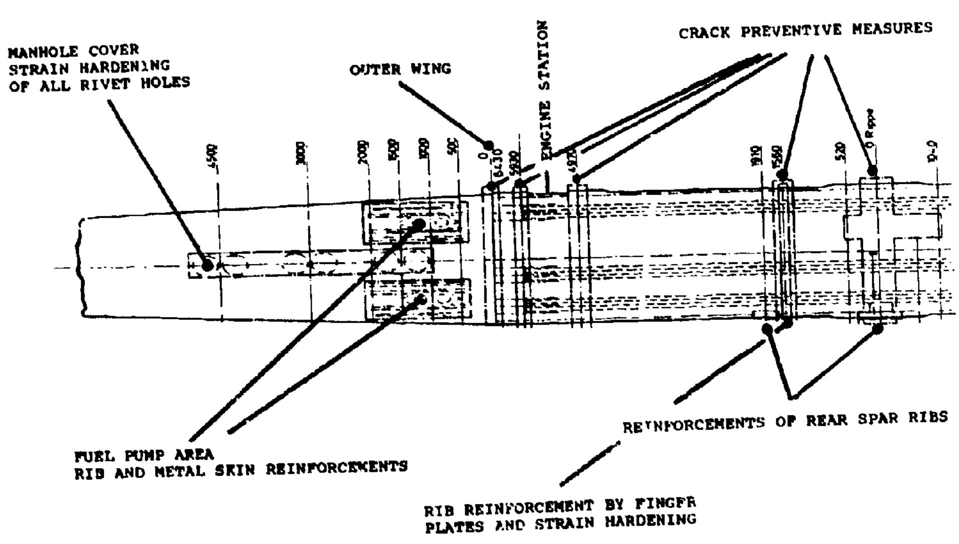


FIG.10 NAVIGATION SYSTEM

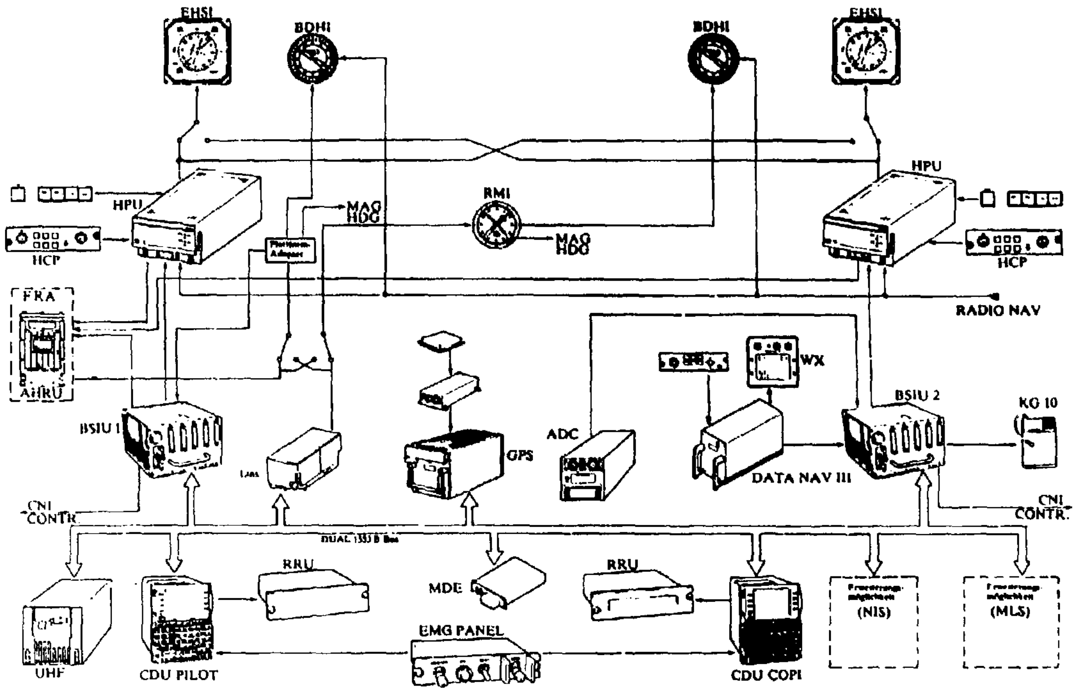


FIG.11 AUTOPILOT/FLIGHTDIRECTOR

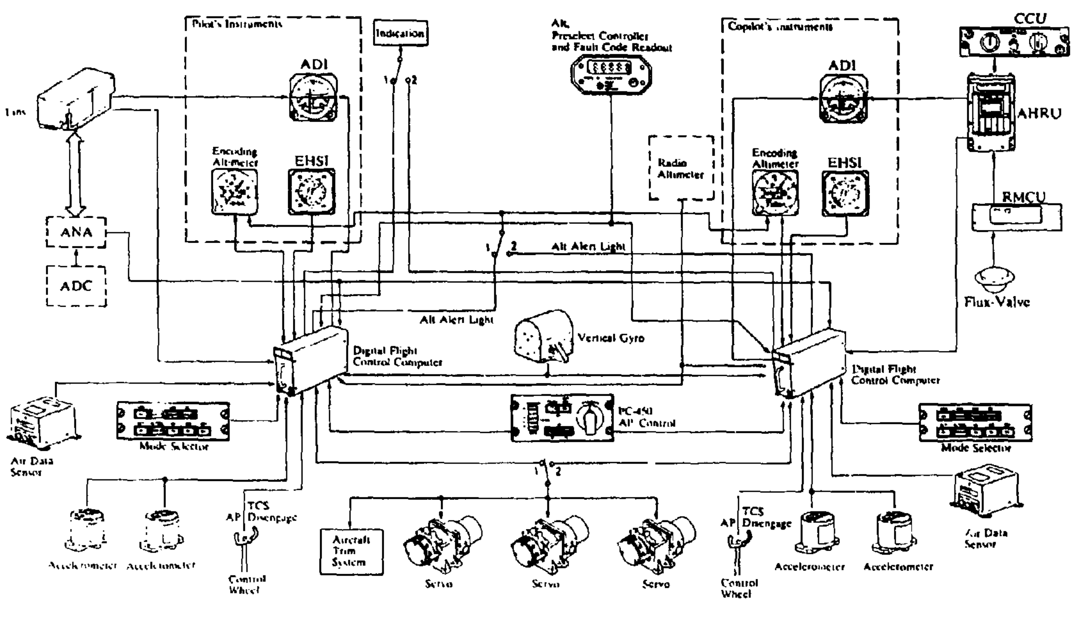


FIG.12 C160 TRANSALL MODIFIED COCKPIT

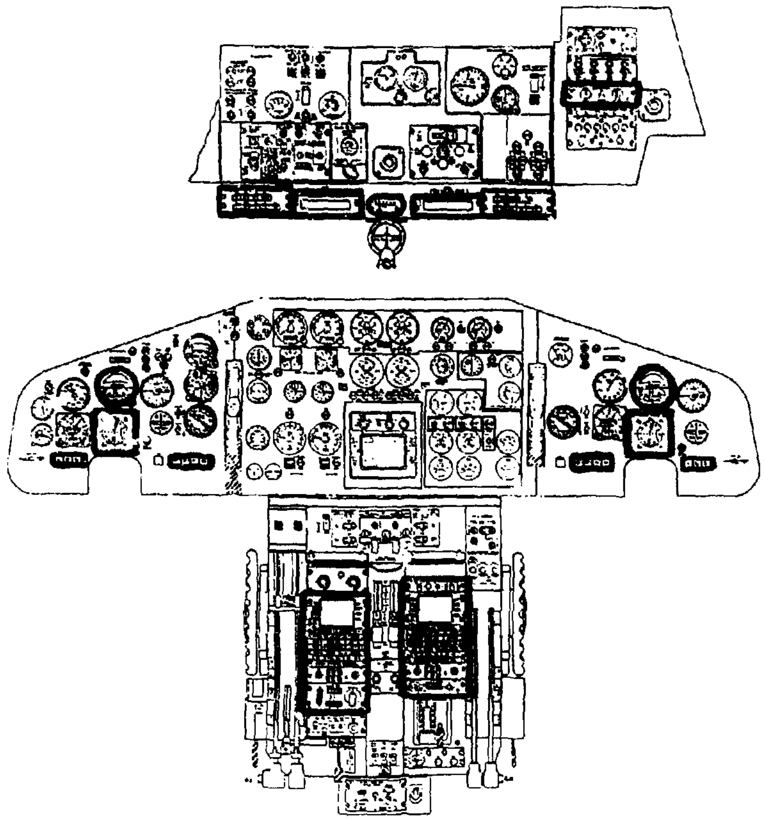
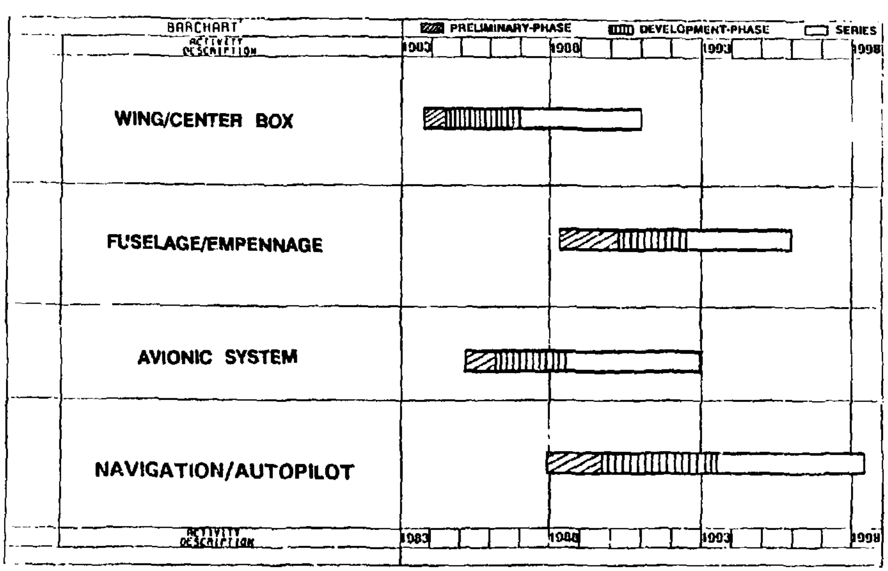


FIG.13 C160 TIME SCHEDULE LIFETIME EXTENSION



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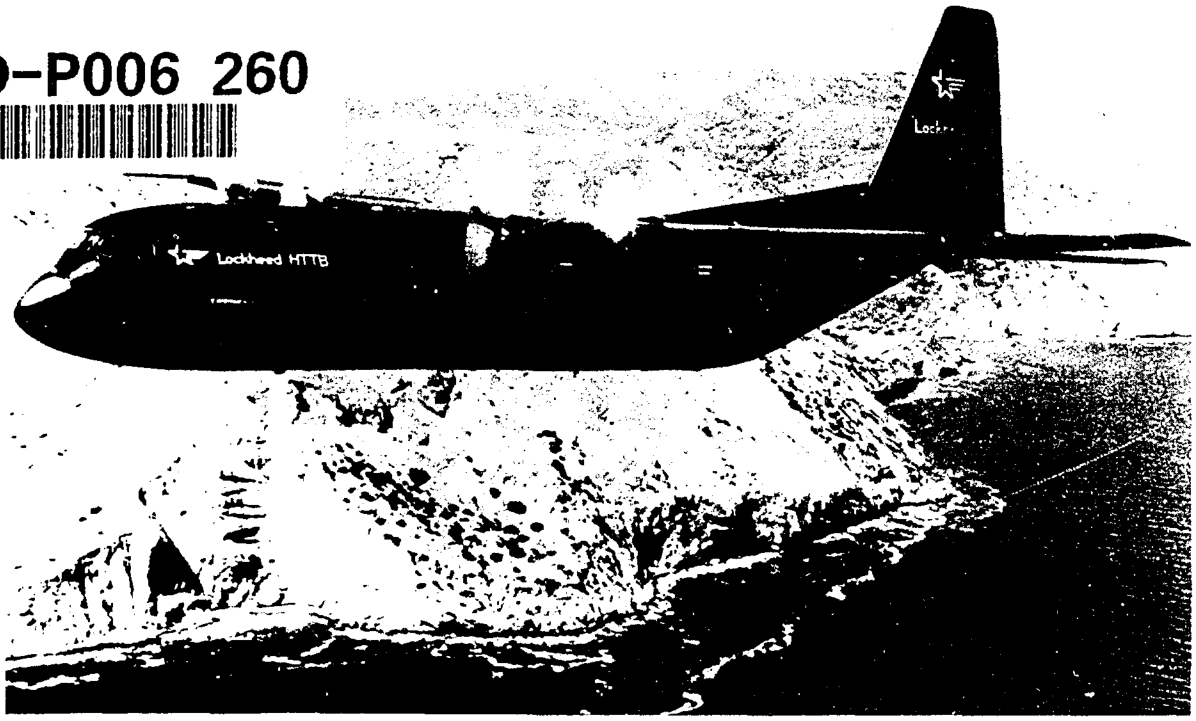

The High Technology Test Bed - A Research Programme For Technology Development

By

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Palmdale, California 93550

Proposed roles for future tactical airlift drive requirements for research and development in the areas of advanced Short Takeoff and Landing (STOL), Electronic Systems, Survivability, and Advanced Cockpit capabilities. A common scenario may involve deep penetration into enemy territory with no air or ground support. The transport may be required to land on bomb damaged runways, highways, or dirt roads. Landing dispersion requirements may not exceed 1,500 feet with a 50 foot obstacle at the runway threshold. The aircraft may have to take on cargo in this area and get airborne again with the same runway requirement.

Lockheed Aeronautical Systems Company began the High Technology Test Bed (HTTB), an Independent Research and Development (IRAD) program, in 1984 to address technologies required for these future tactical transports. The program utilizes a commercial, stretched C-130 transport as the technology focal point. This "Flying Laboratory" is an ideal platform for systems development. The aircraft is highly modified to perform the STOL mission and is fully instrumented with a real time data acquisition system. The HTTB undergoes modification spans followed by flight spans to evaluate systems performance. (25) * Transport aircraft, * Airlift operations.

Program involvement spans the aerospace industry with many companies flying their IRADs on the HTTB. To date these companies number 60 with participation exceeding $13 Million. This participation includes cost shares on systems development, equipment consignments, and sharing of technical expertise. Those involved in the Program to date include:

ABEX
AEROQUIP
AIRCRAFT POROUS MEDIA
AIRDROME PARTS
AIRESEARCH
ALLEN AIRCRAFT PRODUCTS

91 8 23 067

91-08842

ALLISON
ARCO METALS
ARKWIN IND.
BARRY-WRIGHT CORP.
BENDIX AVIONICS
BENDIX FLUIDS
BENDIX GUIDANCE
COLLINS AIR TRANSPORT
COLLINS GOVERNMENT AVIONICS
CRAIG SYSTEMS
DECOTO
E-SYSTEMS
FLIGHT DYNAMICS, INC.
GEC AVIONICS
GOODYEAR
GREENE, TWEED
HAMILTON-STANDARD
HONEYWELL
HONEYWELL-DEFENSE AVIONICS SYSTEMS
HOWELL INSTRUMENTS
HYDRO-AIR
KELSEY HAYES
LITTON AERO PRODUCTS
LORD CORP.
MAGNAVOX
MARQUARDT
MENASCO
METAL BELLOWS CORP.
NATIONAL WATERLIFT
PHOTOTONICS
PACIFIC SCIENTIFIC
PNEUDRAULICS
PUROLATOR
OED
RAYCHEM
RESISTOFLEX
ROSEMOUNT
SANDVIK SPECIAL METALS
SCHAEVITZ ENGINEERING
SIGMA-NETICS
SPECO
SPERRY-DEFENSE SYSTEMS
SPERRY-FLIGHT SYSTEMS
STERER ENGINEERING
SUNDSTRAND AVIATION MECHANICAL
SYMETRICS
T A MANUFACTURING CO.
TELEDYNE LINAIR ENGINEERING
TEXAS INSTRUMENTS
TITEFLEX
TYEE
UTAH RESEARCH & DEVELOPMENT CORP.
UNISYS
VICKERS, INC.

In addition to the vendor participation, pilots from various U.S. and international agencies lend support to the program. These pilots provide Lockheed with an independent evaluation of the pilot workload. As new systems mature during flight test, the pilots are invited to fly the modified aircraft and comment on the performance, handling qualities, etc.

STOL MODIFICATION

The HTTB has undergone four modifications with the most recent to achieve STOL performance. The control surfaces and mechanical flight controls have been altered significantly, Allison T56 Series IV Engines have been installed, and a digital flight control system has been added. During flight tests at Palmdale, the HTTB shattered three world records for STOL-class aircraft performance. The aircraft has lifted the greatest weight ever to 2,000 meters in the STOL-class, lifting 14,220 lbs., smashing the old record of 4,500 lbs. held by a Soviet P-42. It has set two STOL-class records in the climb categories, reaching 6,000 meters in 7 minutes 21 seconds and 9,000 meters in 13 minutes 21 seconds. In this STOL configuration, the HTTB

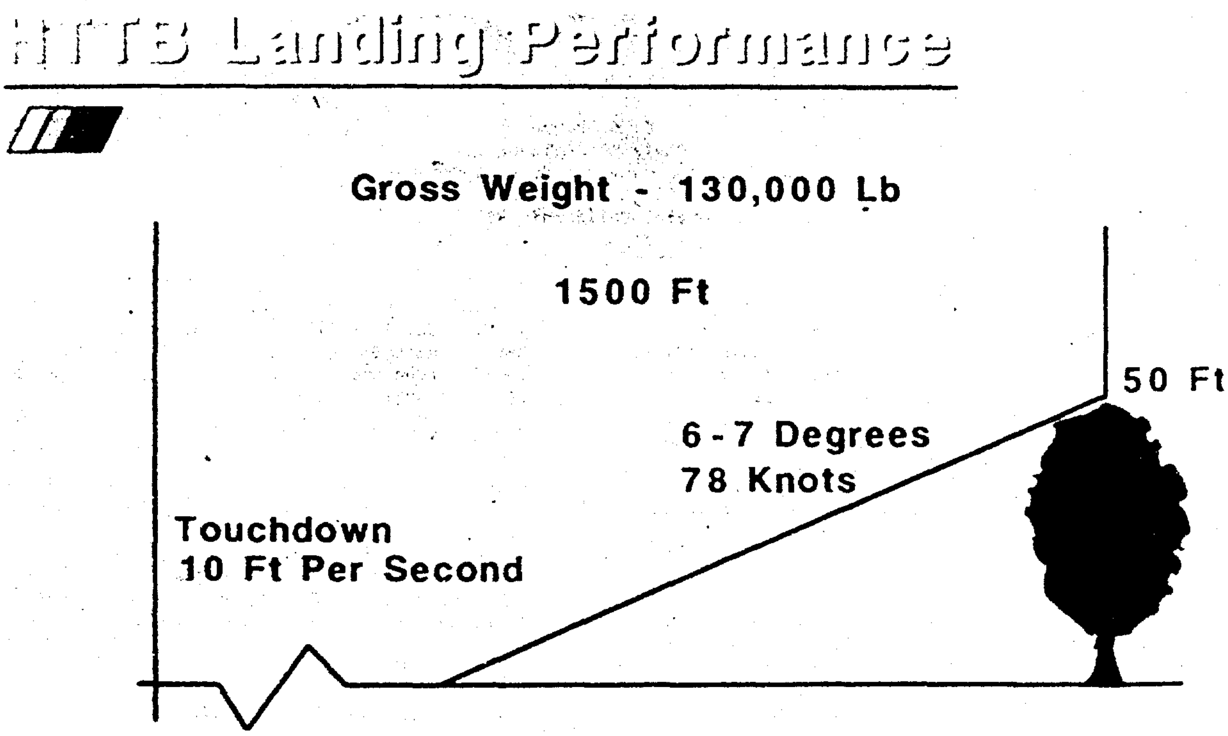


FIGURE 1. STOL Landing Profile

will fly the landing profile illustrated in Figure 1. This profile proposes an 80 knot approach with a glide slope of 6-7 degrees. Sink rate approaches 14 feet per second with ground effect reducing the sink rate to approximately 10 feet per second at touchdown. The aircraft pitch attitude will be approximately 1 degree nose up with no flare.

Control Surface and Mechanical Flight Control Modification

The control surfaces on the HTTB are modified, Figure 2, to include a chambered leading edge allowing aircraft nose up trim for no-flare landings. Spoilers on the wing upper surface provide direct lift control and, in concert with extended chord ailerons, enhance roll control in the low speed regime. The rudder chord is also extended to improve low speed control. A high sink rate landing gear is incorporated with a floating piston arrangement to separate the air charge from the oil for enhanced rough field operations. A double slotted flap assembly, detailed in Figure 3, provides the high lift landing configuration. Horsals and a dorsal improve airflow in the empennage area with the flaps fully extended.

The mechanical flight control system is also modified. All surfaces are fully powered as opposed to the original boosted systems. The tabs on the elevator and rudder are fly-by-wire through the digital flight control system (DFCS) and serve a dual function. They aerodynamically balance the control surfaces and provide emergency surface position control in the event of two hydraulic system failures to a surface.

Complex mechanical systems sum pilot, trim, and DFCS stability augmentation system inputs for the elevator, rudder, and aileron hydraulic power control units. These systems also have structural feedback links to prevent the possibility of surface instability. The aileron and rudder control systems use series trim allowing the control shell and pedals to remain centered even with large trim input. The rudder system also incorporates an input limiting function to prevent rudder over control at higher airspeeds. The elevator control system uses a series and parallel trim concept. This approach gives the pilot column movement with trim inputs, but not enough to drive the control wheel into the pilot at large trim inputs normally required for STOL.

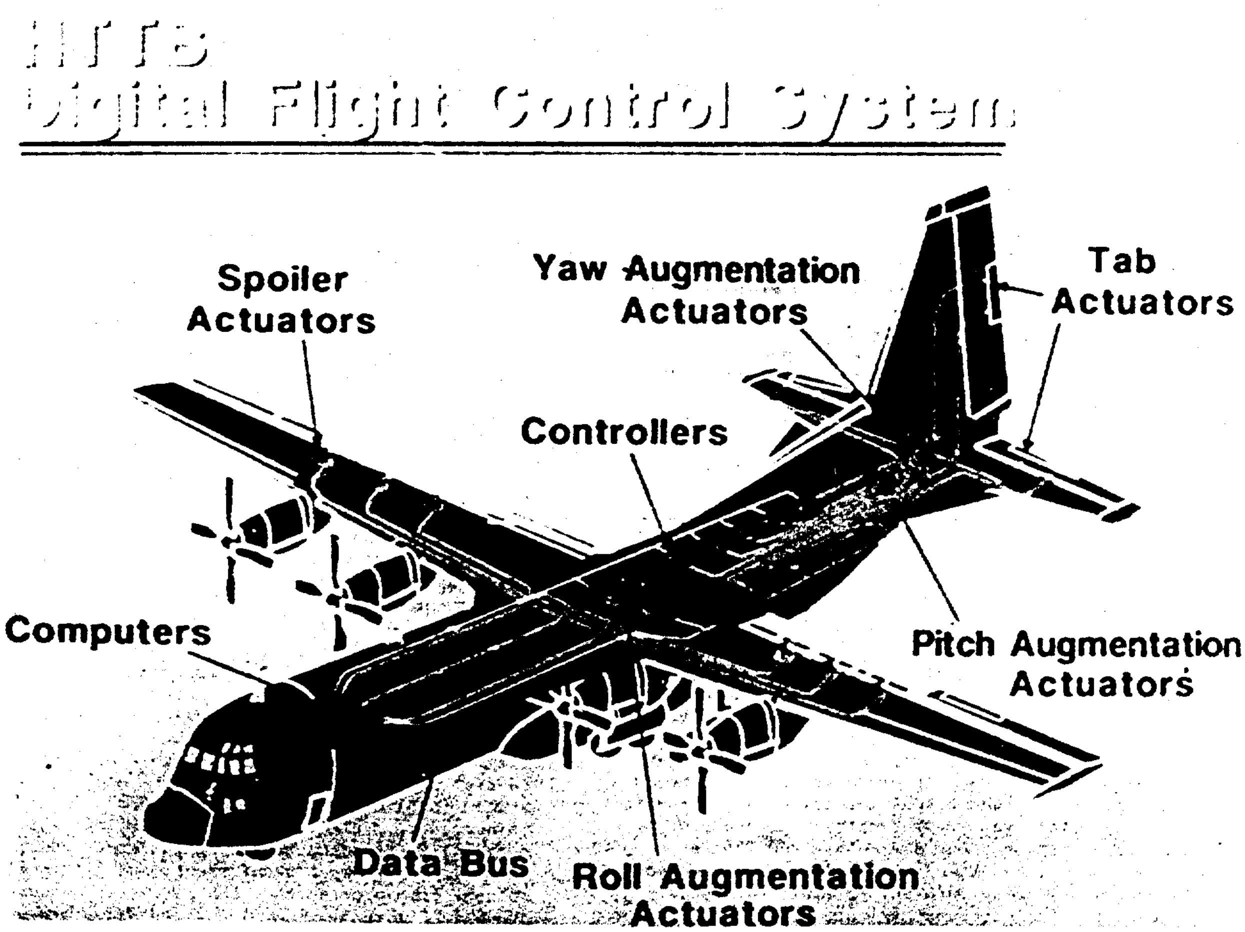


FIGURE 2. HTTB Control Surfaces Detail

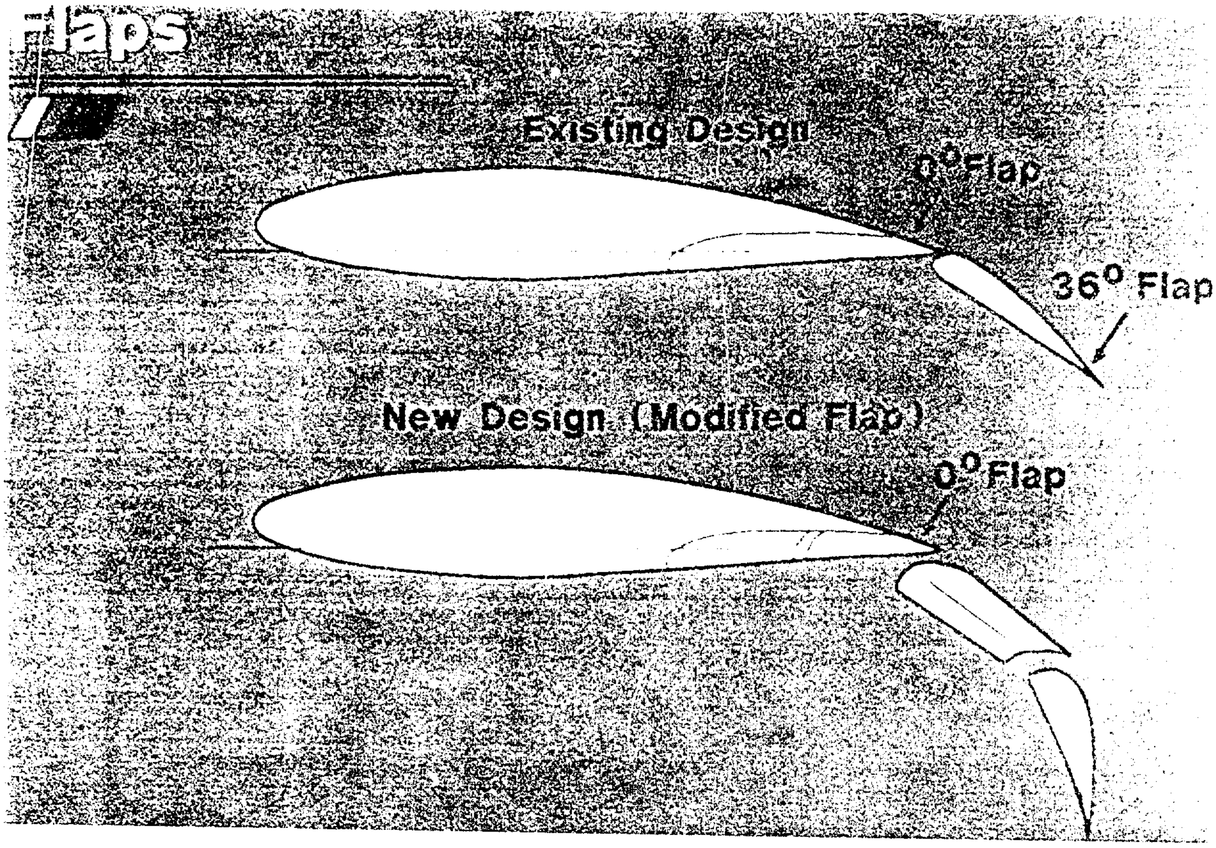


FIGURE 3. Double Slotted Flap

The spoilers are powered by hydraulic systems utilizing a non-flammable fluid chlorotrifluoro-ethylene (CTFE). Unfortunately, the fluid weighs 2.5 times the weight of the current hydraulic fluid. Therefore, system pressure is increased to 8,000 psi to reduce system volume. Three independent hydraulic systems drive the spoilers under fly-by-wire control through the DFCS. Two are power transfers from 3,000 to 8,000 psi and the third is an engine driven pump. The dual actuator arrangement, shown in Figure 4, allows continued spoiler operation of 4 panels in the event of two hydraulic system failures.

Allison T56 Series IV Engines

The Allison T56 turboprops, which power all C-130 aircraft, have been in continuous development and production since the first C-130 was produced at Marietta in 1955. Since then they have benefitted from several major development upgrades shown in Figure 5. The latest T56 production variant offers a 25 percent power increase and a 13 percent reduction in fuel burn over the engines currently in the latest C-130H. It was developed for the U.S. Navy E-2C Hawkeye, carrier-borne, AER aircraft to enable high gross weight carrier take-off with one engine out on a hot day. This new T56 is called the Series IV and, like all its predecessors, it can be installed into any aircraft currently powered by T56 turboprops (Figure 6).

The T56 Series IV turboprop derives its improved performance from modern technology improvements in the compressor, turbine and control system. These improvements are illustrated in Figure 7. The new 14-stage compressor has demonstrated the highest average stage efficiency, in its size class, of any compressor currently in production. Turbine temperature has been increased to raise the power rating; however, advanced turbine cooling technology results in blade metal temperatures lower than those of the current C-130 T56 engine. This feature, coupled with the use of single-crystal alloy blades, also significantly improves turbine life and engine reliability. A digital electronic supervisory control for the engine fuel metering system has replaced several components which required frequent maintenance. This new system provides a linear engine output torque schedule instead of a turbine temperature schedule, and incorporates torque and temperature limiting, which eliminates overshoots thereby adding service life and reliability to the engine. In addition, the automatic features also reduce the present flight crew workload. This modern electronic control also provides for an engine monitoring system (EMS) which will allow on-condition maintenance, cycle tracking, diagnostics, and performance trending resulting in large reductions in field maintenance requirements and elimination of some trim procedures. EMS parameter sensors are shown in Figure 8.

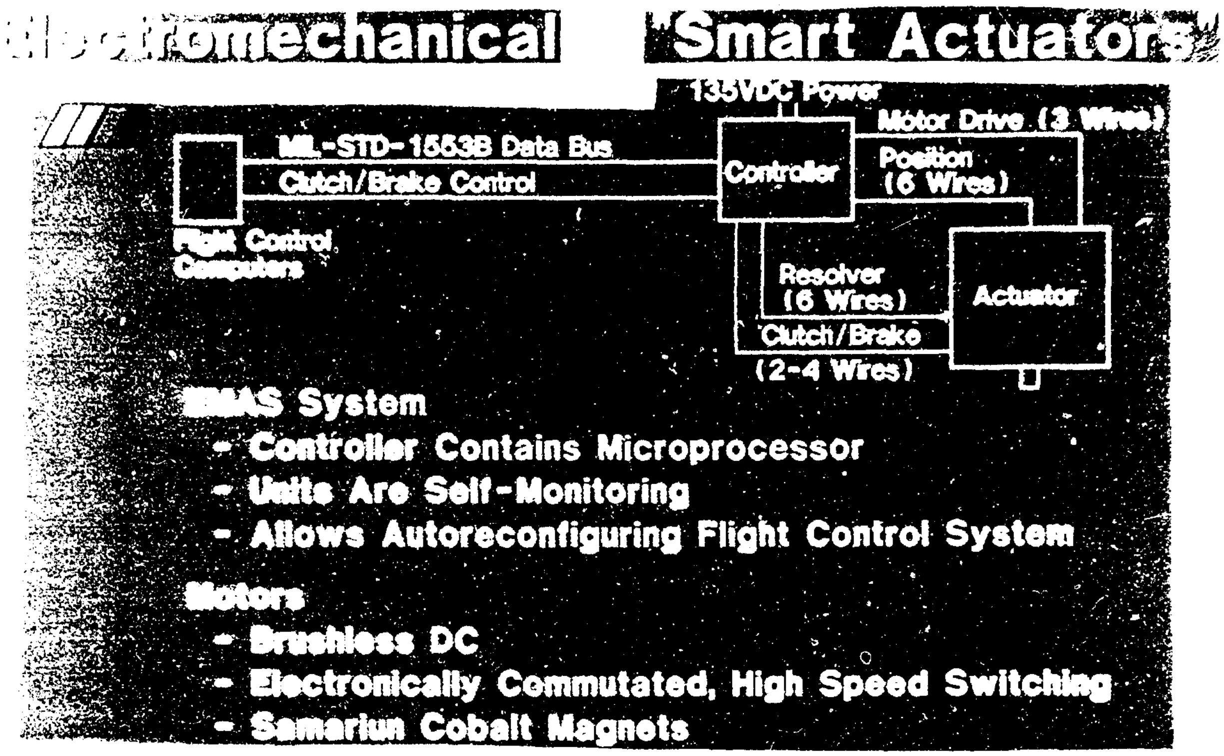
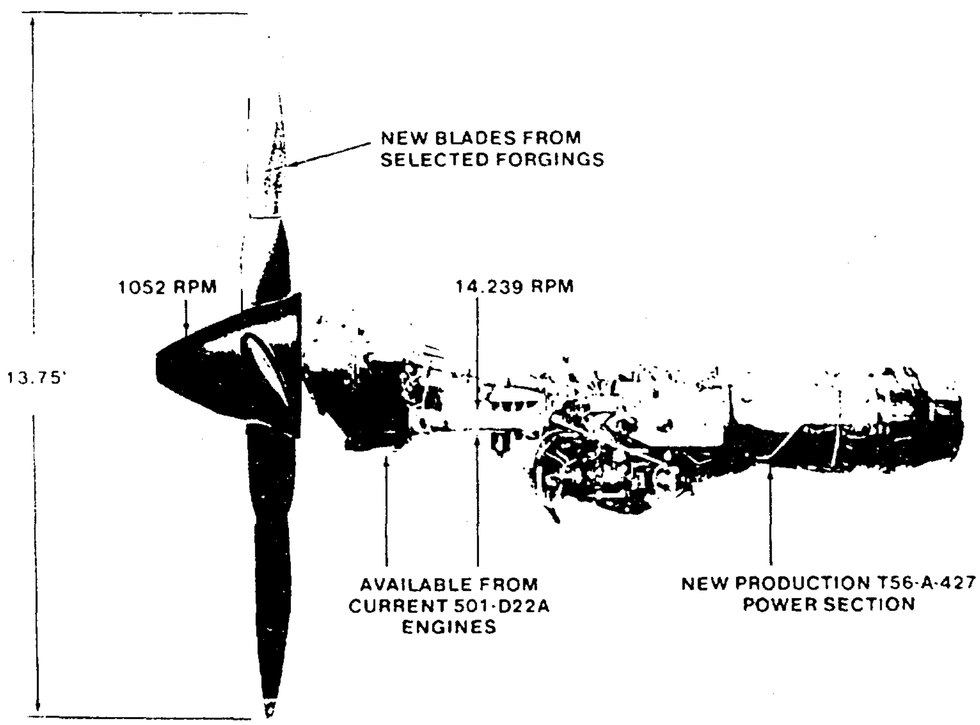
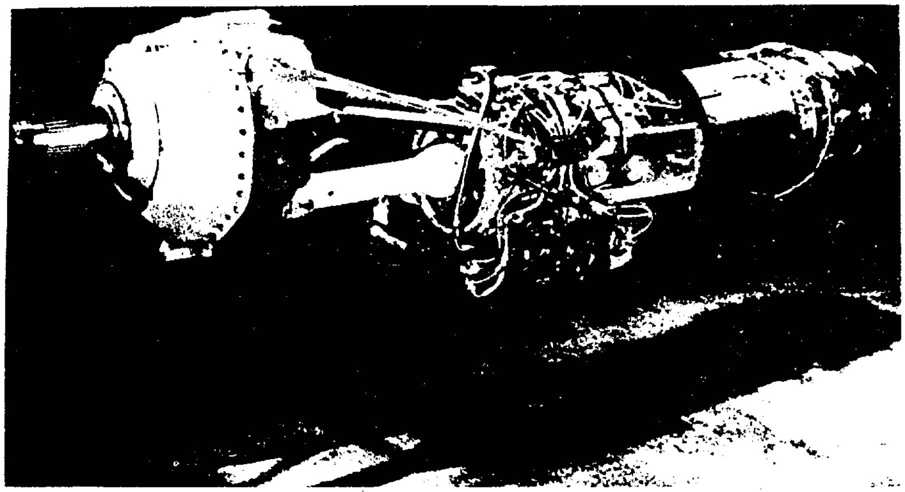


FIGURE 4. Spoiler Actuator



The HTTB benefits from increased performance of the power section and modified propeller.

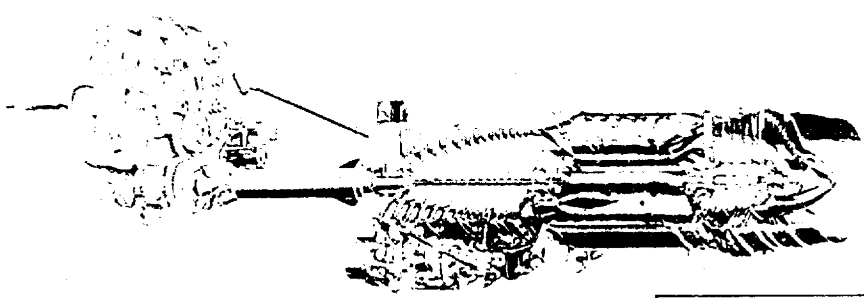
FIGURE 5. T-56 Development Upgrades



The new T56 Series IV turboprop is configured externally like the Series III Engine

FIGURE 6. Series IV Commonality

T56 SERIES IV IMPROVEMENTS OVER SERIES III



GEARBOX

GEAR RATIO CHANGED FOR IMPROVED POWER SECTION OPERABILITY

COMPRESSOR

INCREASED INLET ANNULUS FOR INCREASED AIRFLOW
REBLADED FOR EFFICIENCY
IMPROVED SEALING
IMPROVED MATERIALS

TURBINE

REBLADED FOR EFFICIENCY
IMPROVED SEALING
IMPROVED COOLING
IMPROVED MATERIALS

CONTROLS

SUPERVISORY DIGITAL ELECTRONIC CONTROL
TORQUE LIMITING
IMPROVED ENGINE RESPONSE FOR PROPELLER COMPATIBILITY
RELOCATED THERMOCOUPLES
ENGINE MONITORING SYSTEM–AVAILABLE

COMBUSTION

AIRBLAST NOZZLES FOR SMOKE REDUCTION
IMPROVED COOLING

Significant technical improvements of the T56 Series IV turboprop

FIGURE 7. Series IV Technology Improvements

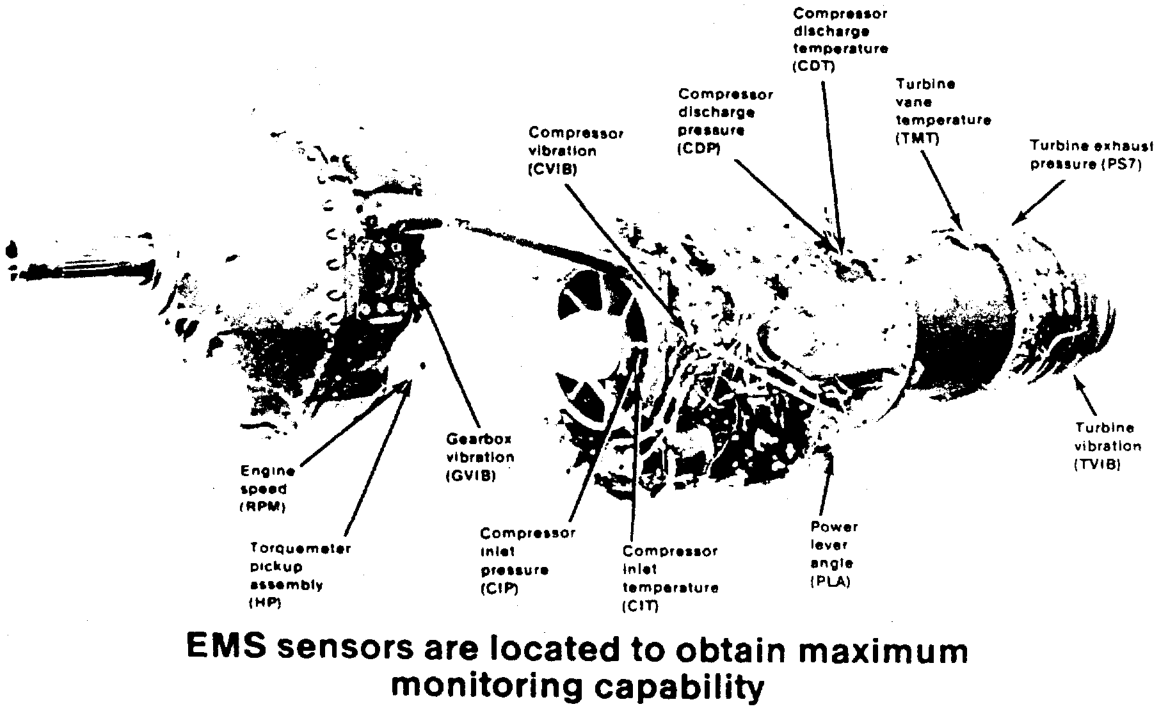


FIGURE 8. EMS Parameter Sensors

The new T56 Series IV turboprop offered increased power to demonstrate short field capability and its ease of fit into the HTTB at minimum cost and aircraft downtime made it a natural for the program. In mid-1988 the decision was made to install the Series IV engines, while the HTTB was in lay-up for aerodynamic mods and avionic changes. The propulsion configuration consisted of new, T56 Series IV power sections (the gas turbine from the E-2C engine), Series III propeller gearboxes and propeller blades which are 1.5 inches longer than standard C-130 propeller blades. The resulting turboprop system was rated at 5250 shaft horsepower (SHP) at sea level takeoff; a 25 percent increase over the Series III installation. A rating comparison at sea level static take off power is shown in Figure 9.

Within six months of the go-ahead decision, Allison delivered the new Series IV engines with refurbished gearboxes to Lockheed. Photographs of the nacelle installation are shown in Figures 10 and 11. In less than three months they had mated the propellers, installed and checked out the engines, and completed the first flight without a hitch. About a month later the HTTB shattered three world records for STOL-class aircraft performance. Performance achievements of the HTTB are shown in Figure 12. This schedule accomplishment is a testament to the ease with which the T56 Series IV can be adapted to the C-130 installation. In addition to the power plant installation, a four-engine EMS system was incorporated, the first of its kind of any turboprop aircraft.

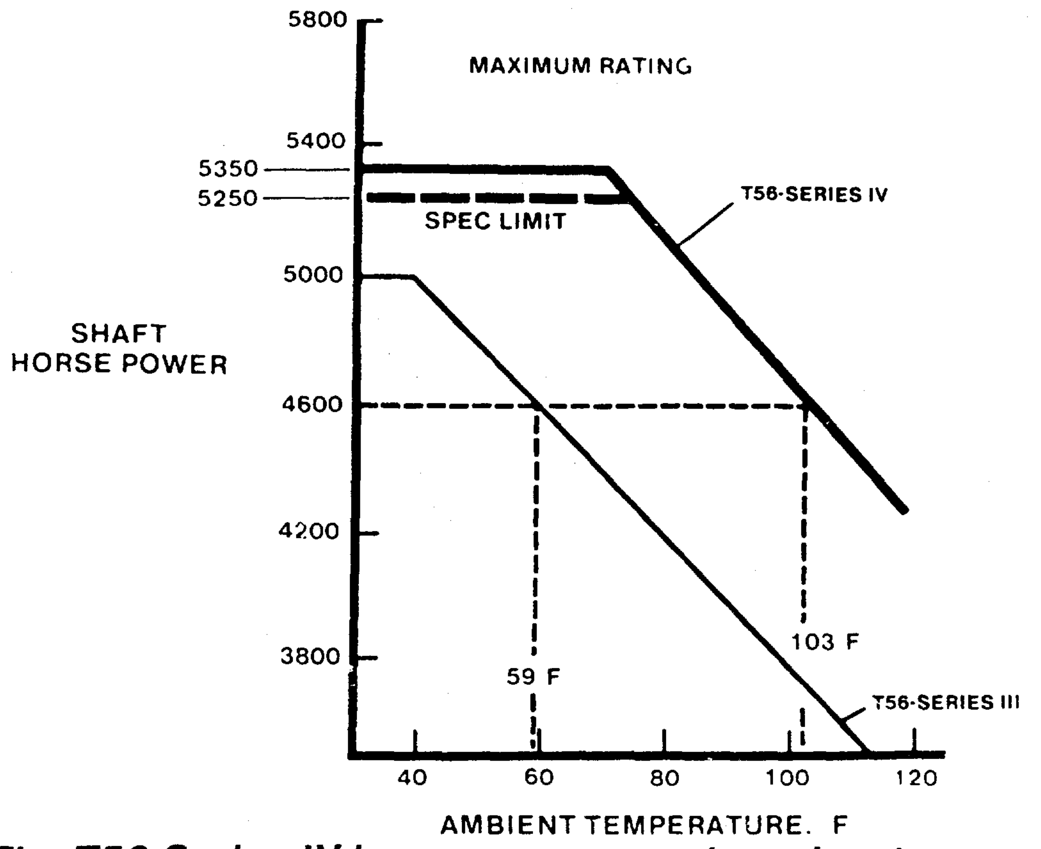
Digital Flight Control System

A digital flight control system (DFCS) is required to extend the flight envelop to the low speed STOL regime. During 1985 and 1986 pilots flew a math model of the flight control system in a flight simulation facility. The facility includes a Singer-Link six-degree-of-freedom motion base coupled with a TI-980B mini-computer. Test pilots rated aircraft handling using the Cooper-Harper rating scale. The chart in Figure 13 indicates that the HTTB will perform better during an 80-knot approach than the basic C-130 at a much higher airspeed. The requirement for the DFCS is evident as well, with the aircraft unacceptable at 80 knots without this system. Current plans are to link the actual flight control hardware with the motion base for pilot-in-the-loop evaluation of the Honeywell system control laws.

The DFCS consists of three computers driving five redundant independent Sundstrand electromechanical systems. A system general arrangement is shown in Figure 14. Three of the EMAS systems provide the stability augmentation functions and the other two EMAS systems drive the tabs on the rudder and elevator. The DFCS also controls the spoiler panels through triplex servo valve motors on the 8,000 psi E-Systems actuators.

A MIL-STD-1553B data bus links the EMAS electronic control units with the flight control computers. These "smart actuators" systems consist of controllers and actuators - one controller per actuator. The controllers house microprocessors which continually monitor actuator position versus computer commanded position.

The flight control computers take inputs from the air data computers, angle of attack sensors, ac acceleration rate and gyro packages, as well as from triplex position sensors on the throttles, forward and aft flaps, rudder and elevator trims, and torque tubes for the rudder, aileron and elevator. These signals are input to control law



The T56 Series IV has more power at sea level static.

FIGURE 9. Static T.O. Thrust Comparison

algorithms to derive actuator position commands. Two computers control the EMAS augmentation system in an active standby arrangement. The elevator servo tab surfaces are controlled independently and the rudder tab is configured in an active-active fail-centered arrangement.

Avionics Improvements

The changes to the flight control surfaces and systems yield an airframe with low speed control capability for very short landing distances. Figure 15 indicates that the HTTB will require about half the landing distance of a basic C-130 aircraft and will be a marked improvement over the C-17 in a similar payload range. This performance coupled with an avionic system capability to accurately determine aircraft position, are required to support deep, covert operations into enemy territory.

The HTTB avionics system shown in Figure 16 is built around a highly flexible cockpit management system using the MIL-1553B data bus. This Collins CMS-80 system allows integration and testing of systems not MIL-1553B compatible through bus system interface units and system interface modules. Currently, the avionics suite includes a MIL-STD-1750A, 1638 processor as a Mission Computer. This unit is the bus controller and computes the flight path based on inputs from various other sensors. The mission computer then drives the head up display computer to provide the pilot with flight cues while he is viewing the outside world.

The navigation sensors being integrated with the mission computer include Honeywell fit, form, and function inertial navigation system (INS) and two Delco Carousel IV inertial navigation systems. One Delco unit is a MIL-STD-1553B compatible, 0.25 nautical mile per hour (NMH) error rate system and the other is a 0.8 NMP unit doppler-damped, to reduce velocity errors. A Litton mini-FLIR is mounted above the cab and its image is rastered on the Flight Dynamics HUD concurrent with the flight symbology.

Currently under development is a Lockheed Adaptive Modular Platform (LAMP) to further enhance the avionics suite. This unit houses a charge couple device camera and a raman shifted ND:YAG laser ranging system. The unit will be mounted just forward of the nose gear extending from the lower part of the radome. The system will be used by the navigator to find and "range to" waypoints. This information will be sent to the mission computer over the MIL-STD-1553B data bus to support flight path generation. Future plans are to develop digital map systems, global positioning systems (GPS), slewable forward looking infrared systems (FLIR), terrain following radar, and other precision sensors to support enroute navigation and autonomous landing guidance into austere landing

New power for the HTTB.

FIGURE 10. Series IV Engine Installation

areas.

Lockheed Airborne Data System

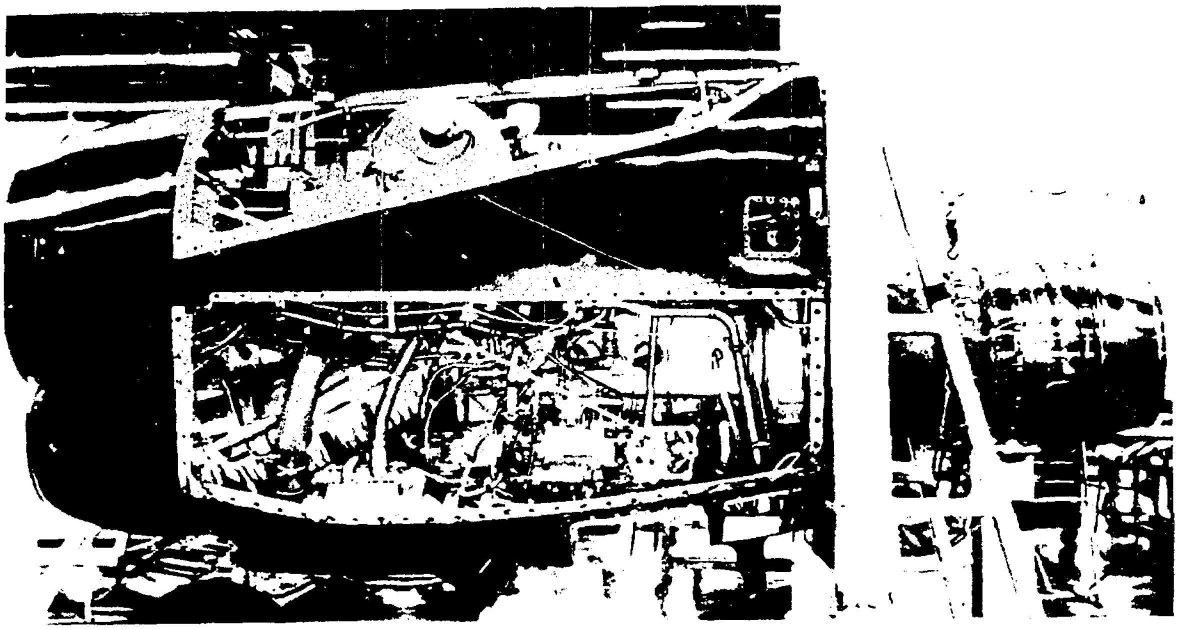
Supporting development of these new technologies, the HTTB is equipped with a real-time data acquisition system. The system, as shown in Figure 17, includes signal conditioning modules, acquisition computers, and a master computer.

Eight, sixteen channel signal conditioning modules are connected to each acquisition computer. Under command of the master computer, each acquisition computer commands its modules to acquire channel 1, then channel 2, and so on. In the time required to acquire 16 channels of data by one module, all data channels from the other modules are acquired within 375 microseconds. The signal conditioning modules also digitize the signals and send the data on to the acquisition computers. In the time between scans, the acquisition computers apply calibration factors and convert the data to engineering units; therefore, reducing the ground data processing time.

The system is capable of acquiring over 1,000 channels at a 20 sample per second rate, and it also can acquire a reduced number of channels at sample rates up to 160 per second.

A processing center supports the data analysis. The center includes a telemetry system, printers, plotters, and CRT terminals. The telemetry system, with color graphic CRT displays, allows engineers to monitor critical data points to determine if the aircraft can proceed to the next flight condition safely. This capability reduces flight test costs by allowing tests up to a hazardous situation without going back to base after each maneuver to analyze the data.

For off-site developmental testing, a data van supports the aircraft. This unit has both data processing and telemetry capabilities, and it can be transported in the HTTB cargo compartment. Upon arriving at the test site, the van with its associated power cart is off-loaded and the telemetry antenna is set up within 30 minutes.



The T56 Series IV installed in the HTTB with ease

FIGURE 11. Series IV Engine Installation

- Program Go-Ahead Sep 1988
- Engines Installed in HTTB Mar 1989
- Flight Clearance Tests Apr 1989
- STOL Development Flight Test Started May 1989
- May 19, 1989: HTTB Sets Four New World Records For STOL Aircraft
  - Time-To-Climb To 3000 Meters
  - " " " " 6000 "
  - " " " " 9000 "
  - Greatest Payload Lift To 2000 Meters

    14,220 LB Payload
    Take-Off Distance 1400'
    Landing Distance 950'
- Continuing STOL Development & Flight Demonstrations

The HTTB T56 Series IV Engine Program and Achievements

FIGURE 12. HTTB Performance Achievements

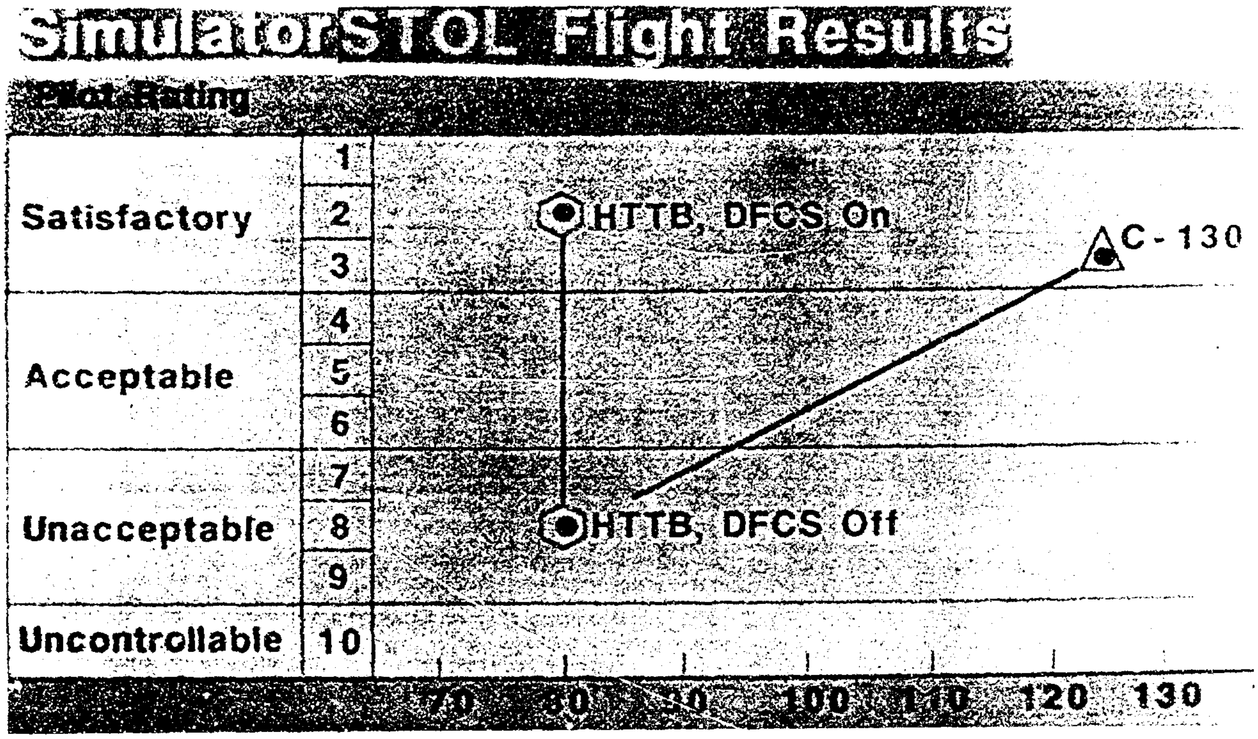


FIGURE 13. Handling Qualities

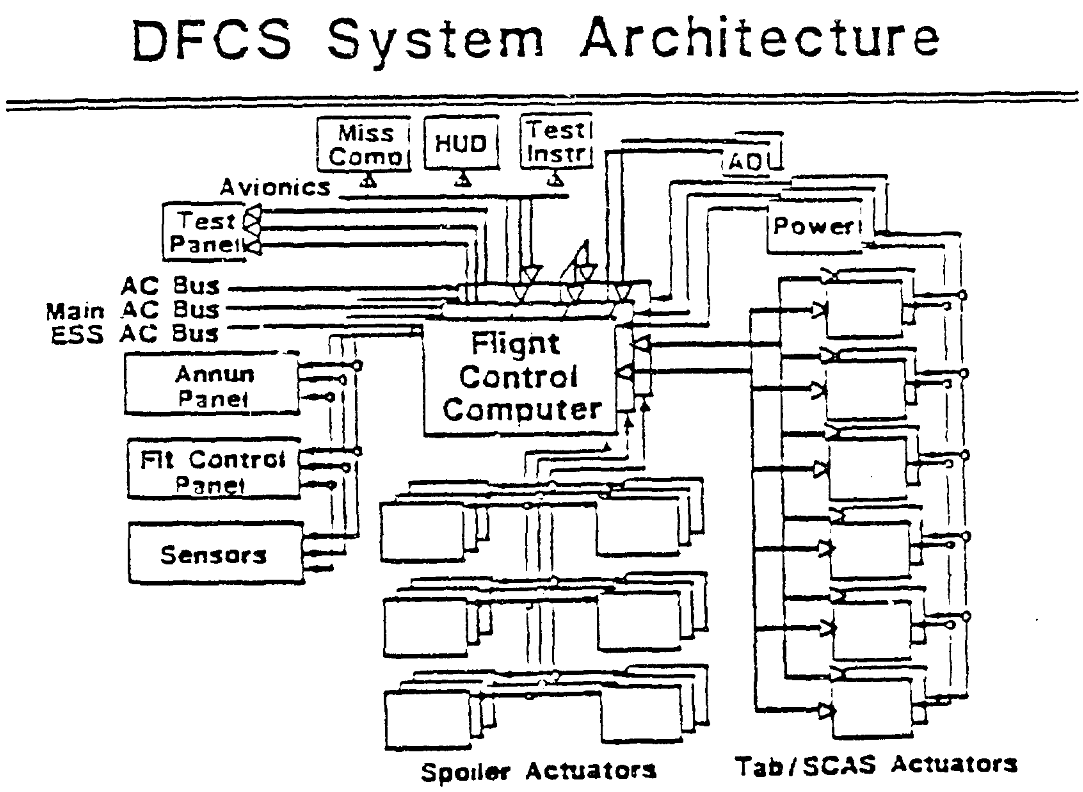


FIGURE 14. DFCS Layout

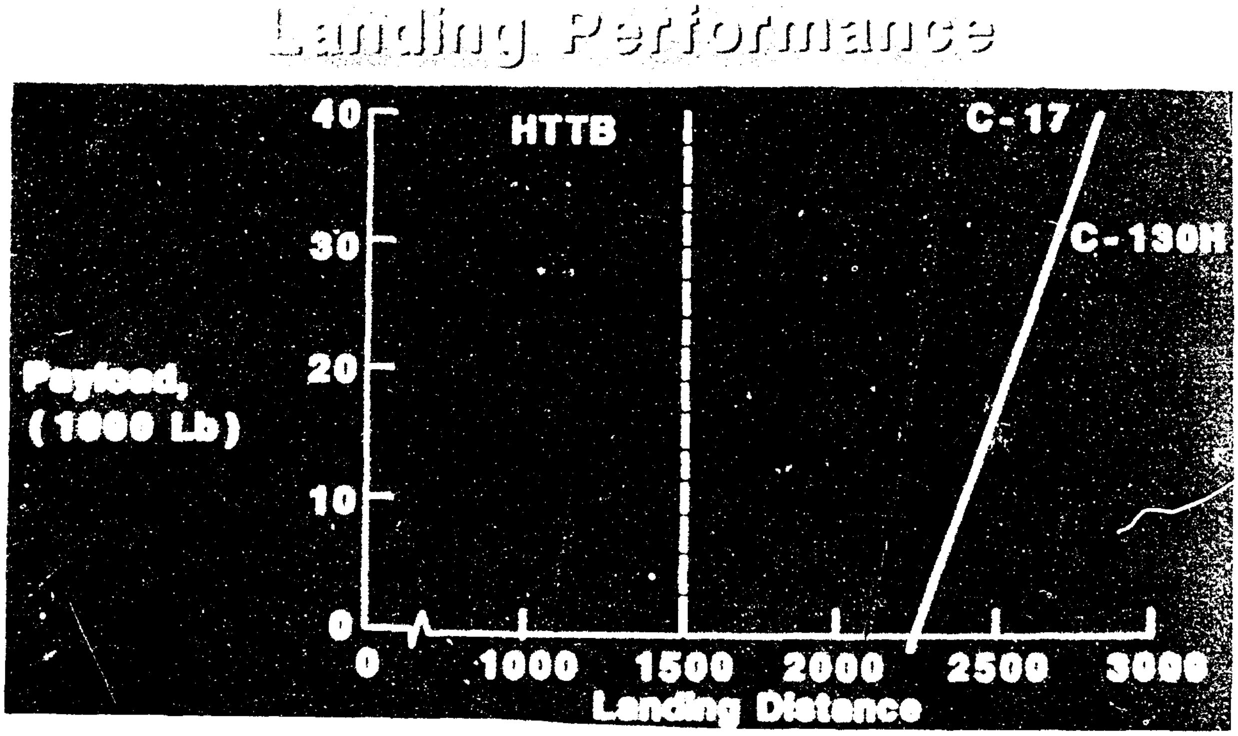


FIGURE 15. HTTB Landing Distance vs. C-130H, C-17

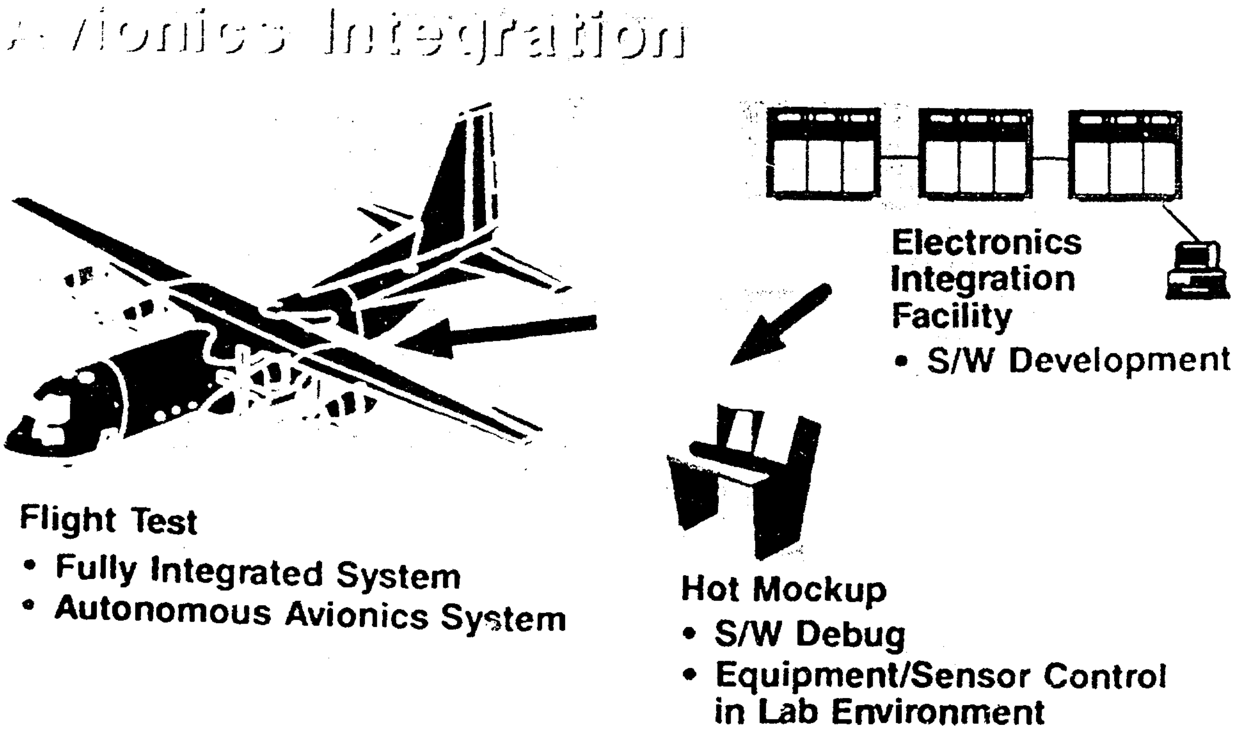


FIGURE 16. HTTB Avionics System

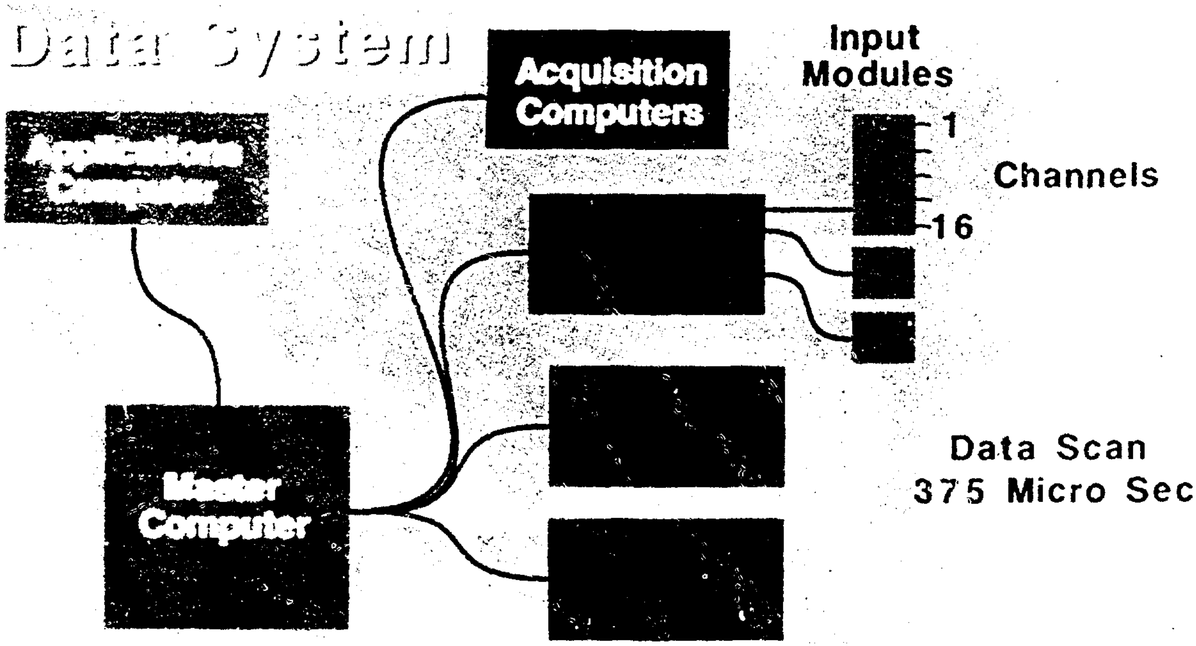


FIGURE 17. Lockheed Airborne Data System

SAMSON POD

During flight tests in 1985, the HTTB supported the SAMSON, Special Avionics Mission - Strap On Now, Program. This program used a modified external fuel pod to house a turret mounted FLIR and a ram air turbine, Figure 18. The turbine turned a generator providing power for the FLIR system and three IR receiver/transmitters. FLIR control and video signals were transmitted over an IR data link between the pod and the airplane fuselage.

The role of the SAMSON system is to perform multiple missions with a single aircraft. By simply changing the pod the aircraft could be ready for a sea search mission, an electronic countermeasure mission, etc.

Sensor Evaluation Platform

A long term goal is to develop the aircraft to a sensor evaluation platform as illustrated in Figure 19. Pod mounting locations between the engines currently exist. At this location, payloads up to 45" diameter, 25' in length, and 8,000 lbs. can be mounted. Plans are to install mounting locations outside the outboard engines.

The existing avionics rack can support fully integrated systems or a hot mockup can support autonomous development. The hot mockup is a portable unit with a MIL-1553B data bus, a control and display unit, a mission computer, a bus system interface unit, and mounting provisions for radios and inertial systems. A software integration facility supports avionics integration tasks. As the software is developed, the various sensors can actually be controlled on the hot mockup. The hot mockup can be loaded into the cargo compartment of the HTTB to serve as a control console for pod mounted sensors providing a completely autonomous avionics system. The unit can also be linked to the airborne data system to support data acquisition and analysis of these new systems and sensors. This concept allows for technology assessment without affecting aircraft safety and without expensive aircraft mods or excessive down time.

Flight Testing

The HTTB first flew on April 24, 1988 following the extensive STOL modification. Since that time the aircraft has been cleared for flutter throughout the flight envelope. Full stalls have been accomplished in all modes except STOL flaps. The flaps have been operated to the full STOL position and cleared to the limit speed of 110 knots with maximum engine power. The three 8,000 psi hydraulic systems have been interfaced with the DFCS. All avionics are flight worthy and development continues. The DFCS has been driving the servo tabs on the elevator, but is locked out in other functions at this time.

As simulator activities prove out the flight control hardware, the aircraft will progress to inflight checkout of the rudder tab and the DFCS stability augmentation functions.

Conclusion

The HTTB Program allows for continuing research of many technologies at minimal costs. The program uses the battle proven C-130 platform as the technology integration focal point andprovides researchers at Lockheed and other companies and agencies the opportunity to assess rapidly changing technologies in a flexible environment. Lockheed invites interested companies and agencies to participate in the program to advance the technologies required for future tactical systems.

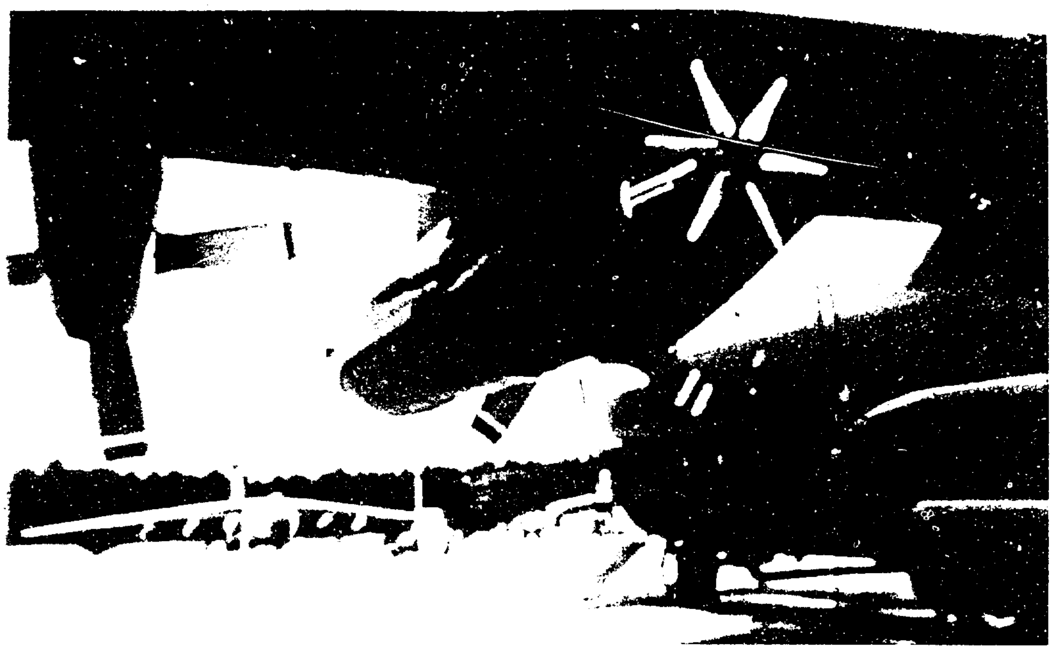


FIGURE 18. Special Avionics Mission Program – Strap On Now (SAMPSON)

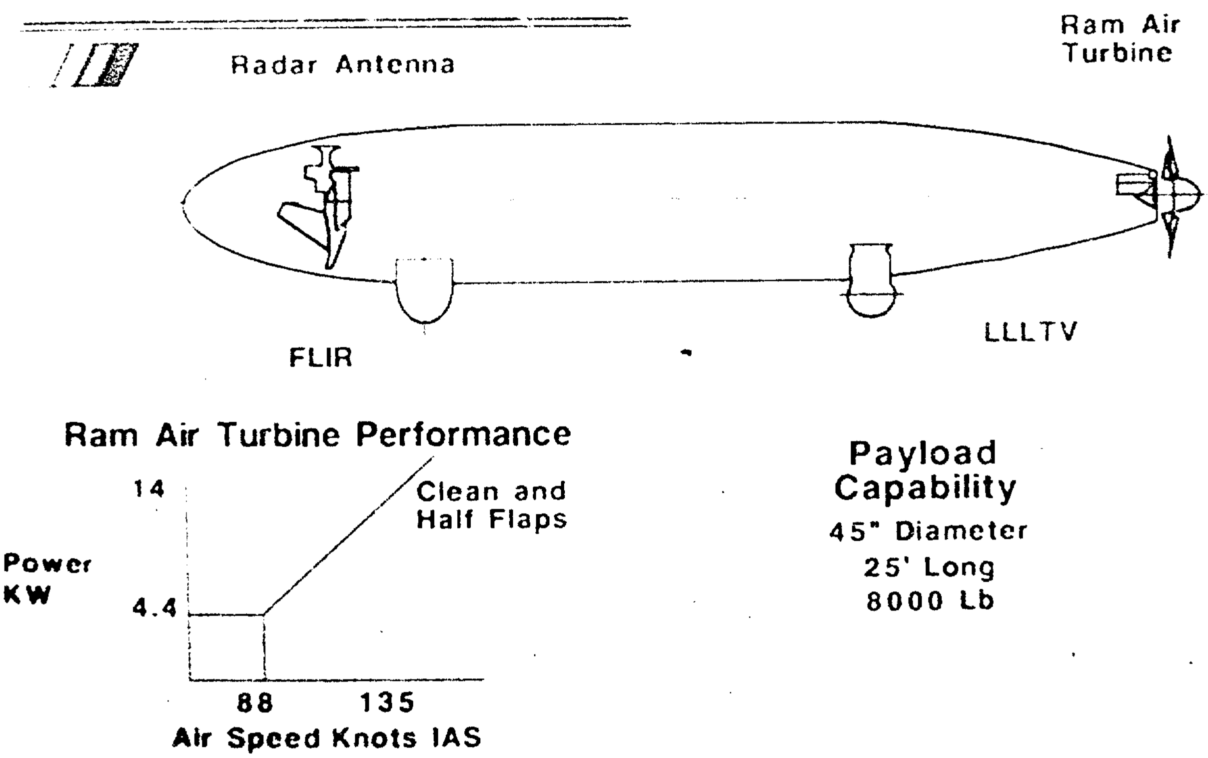


FIGURE 19. Sensor Evaluation Platform

THE C-17: MODERN AIRLIFTER REQUIREMENTS AND CAPABILITIES

AD-P006 261

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McDonnell Douglas Corporation
Long Beach, California 90025 USA

SUMMARY

Modern airlift technology offers defense planners an effective tool for husbanding their resources in centralized locations, yet quickly deploying them to any trouble spot for a deterrent show of force or to prevent an aggressor from consolidating an attack. The newest military airlift aircraft, the U.S. Air Force's C-17, can rapidly move substantial quantities of large, modern weaponry in fighting condition any place on the globe. The new air transport capability capitalizes on proven technology which is currently incorporated into today's commercial airliners and front-line fighter aircraft.

This paper describes how existing technology is being applied on the C-17 to satisfy the requirements for modern military airlift aircraft. The C-17 expands the traditional airland and airdrop modes of transportation to include direct delivery of large outsize equipment. This airlifter transports M-1 tanks, AH-64 helicopters, and Bradley Fighting Vehicles and delivers them to semiprepared austere airfields as small as 94 meters by 27 meters. The aircraft is operated by a crew of three employing fly-by-wire and mission computer technologies to integrate information and operations. (25) * Transport aircraft, * airlift operations, C-17 aircraft.

BACKGROUND

The NATO commitment that binds our nations together is fused with a common resolve to safeguard freedom by maintaining a deployment capability for modern forces in support of mutual defense. The recognition of this capability has successfully deterred a numerically superior force from aggression for the last four decades. At a time when tensions appear to be relaxing in Europe, politicians are encouraging a reduction of military budgets by delaying modernization and decreasing the size of our forces. The impact of these actions on our military capabilities can only be deleterious.

As force sizes are reduced, older equipment will be retired from NATO, leaving smaller but somewhat more modern forces for defense. These smaller allied forces will still face the challenge of defending our common interests and must therefore continue to make maximum use of modern technology.

Conflicts around the globe during the last two decades have demonstrated that speed and surprise contribute immeasurably to victory. Where they were lost, victory was still attainable but at a very high price. Land forces can attain speed and surprise only with airlift, except for countries with mutual borders. And the airlift must be capable of delivering all their new weapon systems to the battlefield.

The C-17 aircraft has been designed to satisfy all the requirements for airlifting modern forces. This paper focuses on those requirements and how the aircraft design capitalizes on proven technology to satisfy them.

REQUIREMENT

Deployment concepts and strategies are based on the premise that the selected mobility option should be responsive, reliable, and affordable. To be responsive, airlift must be able to rapidly move all required land forces and equipment, sometimes over long distances, in all weather — day or night — and deliver them where the local commanders need them. Airlift must also offer a variety of delivery options in the forward area to exploit dynamic battlefield conditions and be capable of operating through and surviving in delivery areas. Both the aircraft and support systems need to be relatively simple to operate and be dependable — to a very high degree. Further, the airlift system must place a minimal burden on manpower and other resources for both training and operations.

The current airlift capability does not meet these requirements (Figure 1). Speed and surprise are sacrificed as C-5 and C-141 aircraft cannot use the small airfields which are often found throughout a deployment area. Only relatively short-range aircraft such as the C-130 can use these small airfields. For U.S. forces, a time-consuming two-step process is now necessary in which C-130s are repositioned for forward deployment, and intercontinental C-141 and C-5 aircraft then bring the forces to a large transshipment base. Since the C-130 aircraft can only deliver smaller equipment, much of our land force equipment must be transported forward over road or rail, sacrificing speed and surprise.

Future airlifters will span long distances, land in small fields, and deliver large equipment, thereby achieving speed and surprise (Figure 2). Modern airlifters will direct deliver over long distances because they are designed for this type of mission. The aircraft that will accomplish this task is the C-17, which McDonnell Douglas is building (Figure 3).

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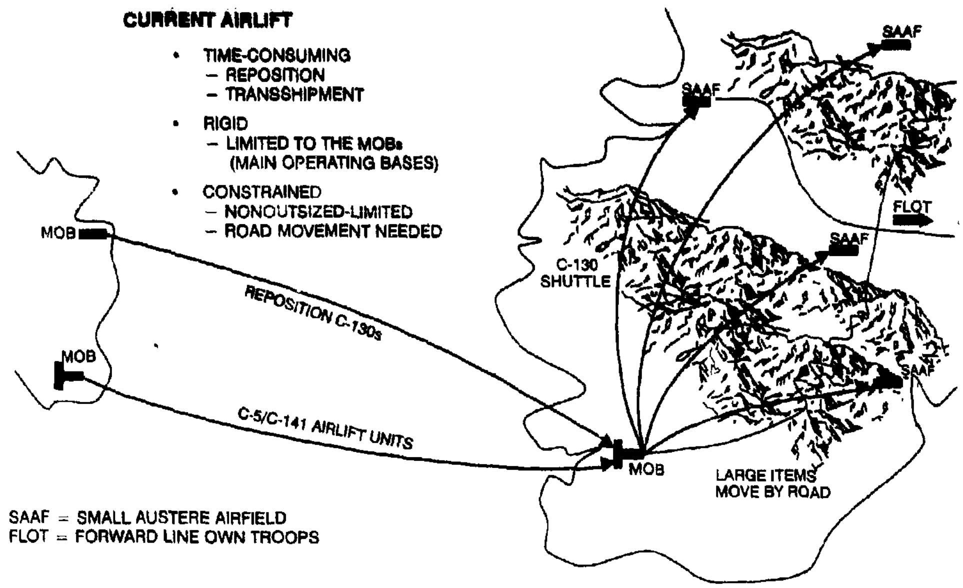


FIGURE 1. SHORTCOMINGS OF CURRENT AIRLIFTERS

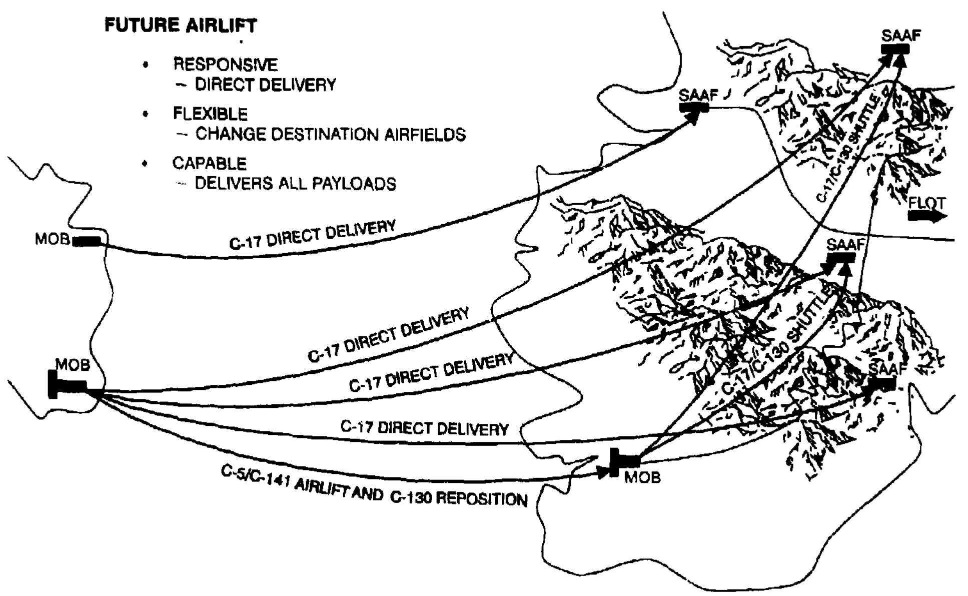


FIGURE 2. CHARACTERISTICS OF FUTURE AIRLIFTERS

TECHNOLOGY

To illustrate how technology has improved the performance of airlift aircraft, consider the DC-3, or C-47 as it was known in uniform. The C-17 is three times as long, has twice the wing span, can deliver a payload 18 times greater than the DC-3, and can take off and land on a shorter runway.

A comparison with current Air Force airlift aircraft shows the C-17 has approximately the wing span of a C-141, the interior width of a C-5, and the landing distance of a C-130 (Figure 4). The technology that enables a large aircraft to land on short runways is called propulsive lift. This technology was proven in more than 800 flight hours during the late 1970s by the McDonnell Douglas YC-15. In propulsive lift, the flap is lengthened to extend into the engine exhaust, and the exhaust is deflected downward along both sides of it. The C-17 flap is about the same size as an MD-80 wing.

The additional lift allows the C-17 to slow to 115 knots and make a no-flare landing at a sink rate of 274.4 meters per minute. A 5-degree approach angle permits the C-17 to cross a 15-meter-high obstacle and still touch down within the first 150 meters of the runway (Figure 5). A conventional aircraft will normally approach the runway at an approach angle of

WING AREA	353 m²	3,800 FT²
WING SWEEP	25 DEG	25 DEG
CRUISE SPEED AT ALTITUDE	0.77 MACH	0.77 MACH
THRUST RATING	18,461 kN	40,700 LB
MAX TOGW	263,083 kg	580,000 LB
MAX PAYLOAD (2.25 g)	78,110 kg	172,200 LB
LOADABLE LENGTH	26.8 m	88 FT
LOADABLE WIDTH	5.49 m	216 IN.
LOADABLE HEIGHT	3.76 m	148 IN.

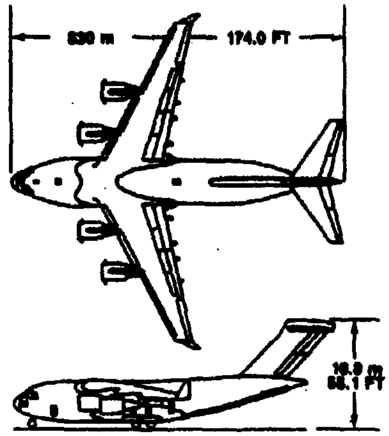


FIGURE 3. CHARACTERISTICS OF THE C-17

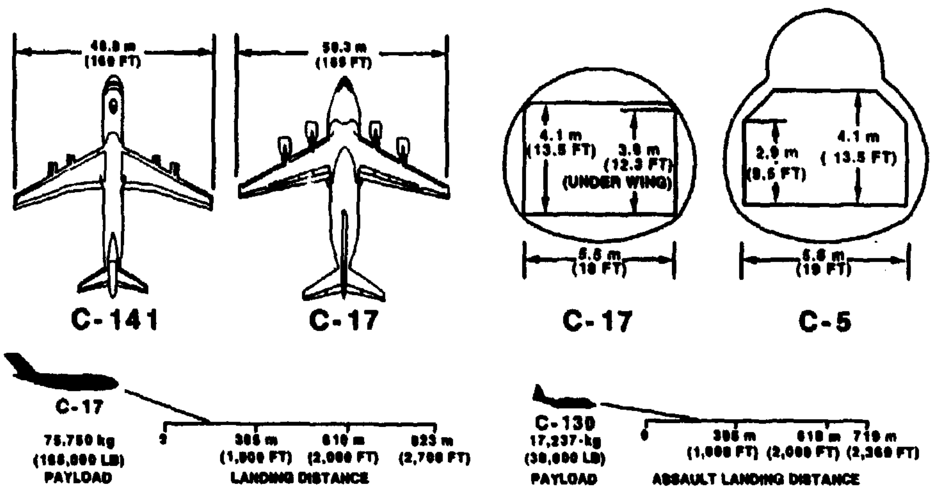


FIGURE 4. COMPARISON OF C-17 WITH CURRENT AIRLIFT AIRCRAFT

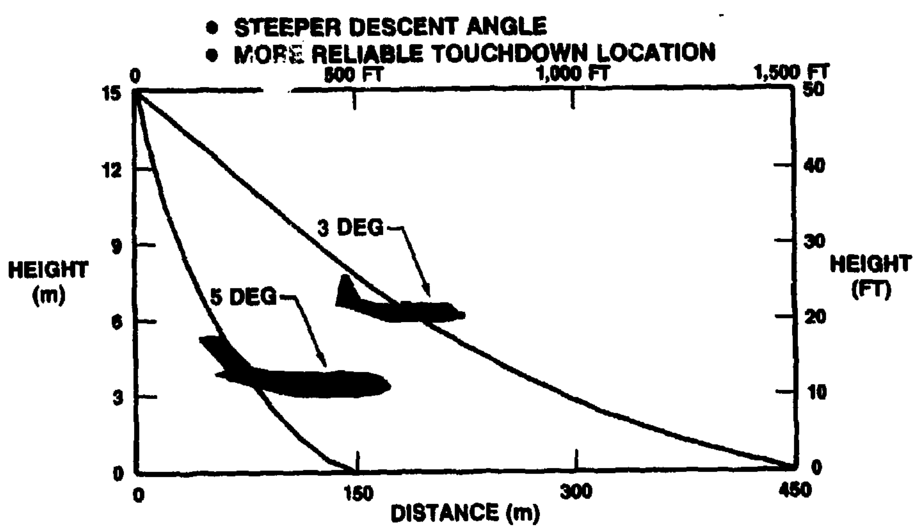


FIGURE 5. APPROACH AND LANDING CHARACTERISTICS

approximately 3 degrees and will accordingly have less control over the touchdown point. The C-17 then employs antiskid brakes and engine reverse thrust to decelerate. The C-17 will deliver its full 78,110-kg payload into a 914-meter-long runway.

The C-17 engines are Pratt & Whitney 2000 series. These fuel-efficient engines are currently in commercial revenue service. More than 300 engines have been delivered to 12 different customers and these engines have accumulated over 1.8 million flight hours. Each engine provides 181.06 kilo-Newtons of thrust, and four of these engines can lift off a fully loaded C-17 in 2,316 meters.

The fuel efficiency of the engines permits the C-17 to transport its maximum payload over 4,000 kilometers (Figure 6). In fact, the C-17 can transport an M-1 Abrams tank nearly 6,000 kilometers. And the aircraft can be refueled in flight for even longer ranges.

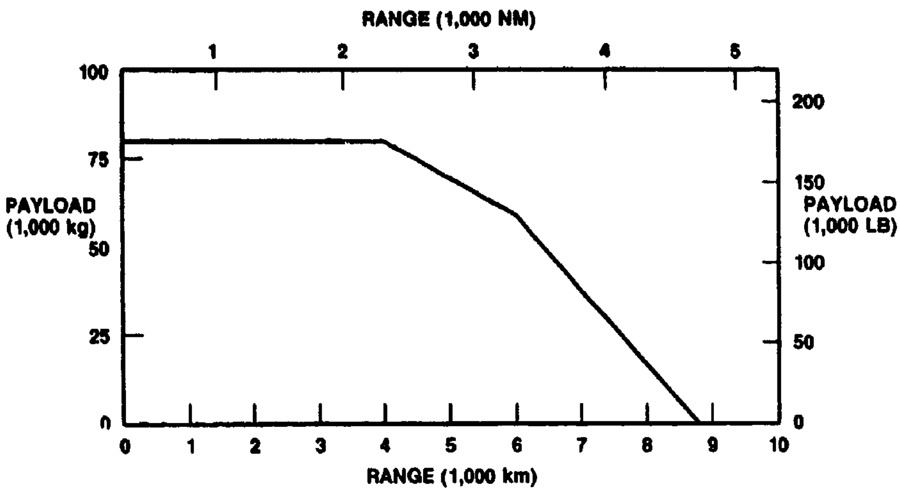


FIGURE 6. INTERCONTINENTAL PAYLOAD RANGE

Once on the ground, the C-17 uses improved technology to operate on narrow runways. The reverse thrust from the engines generates sufficient force to back the fully loaded C-17 up a 2-percent slope. This enables it to completely turn around on a 27.4-meter runway (Figure 7). The narrow gear and high wing allow the C-17 to maneuver on 13.12-meter taxiways. In order to ensure that three C-17s fit on a "typical" 92- by 122-meter parking ramp, the wing span was reduced approximately 3 meters. Winglets were then added to recover the flight efficiency lost with the wing size reduction.

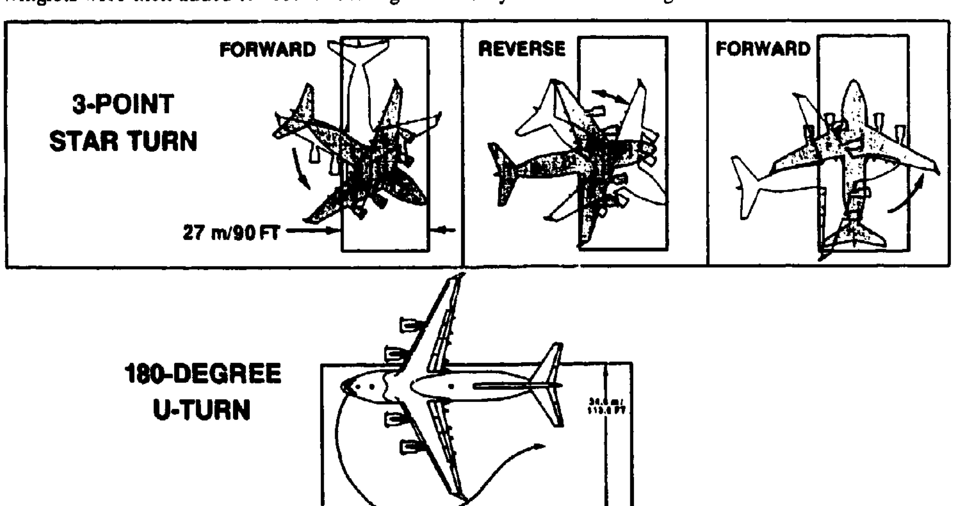
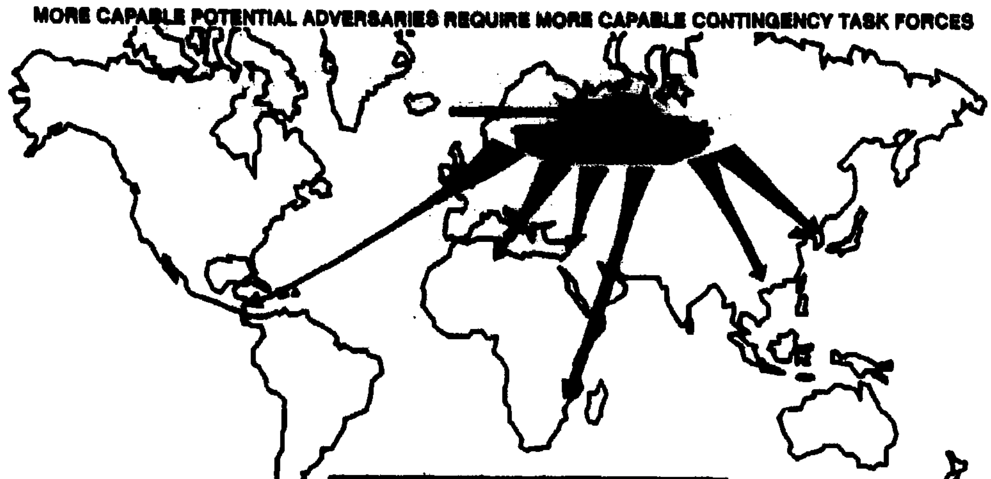


FIGURE 7. C-17 GROUND MANEUVERABILITY

PAYLOAD

While the Soviet threat might be diminishing in central Europe, their armored vehicles are showing up in potential trouble spots throughout the world (Figure 8). In the last decade, more than 40,000 Soviet armored vehicles were exported outside



SOVIET EQUIPMENT DELIVERED TO THE THIRD WORLD - LAST DECADE	
TANKS/SELF-PROPELLED GUNS	7,925
LIGHT ARMOR	14,100
ARTILLERY	20,470

FIGURE 8. SOVIET ARMAMENT EXPORTS

of Europe. The C-17 is designed to transport the modern ground forces equipment that can counter this threat. Armored vehicles such as the M-1 Abrams tank and M-2 Bradley Fighting Vehicle were test loaded into a full-scale cargo compartment mockup. Loading analyses were completed for a variety of armored units such as those equipped with Leopard tanks or Cougar armored vehicles (Figure 9). Analysis shows that a notional 18-tank company could be airlifted in only 19 C-17 loads. Construction equipment loads are also developed (Figure 10).

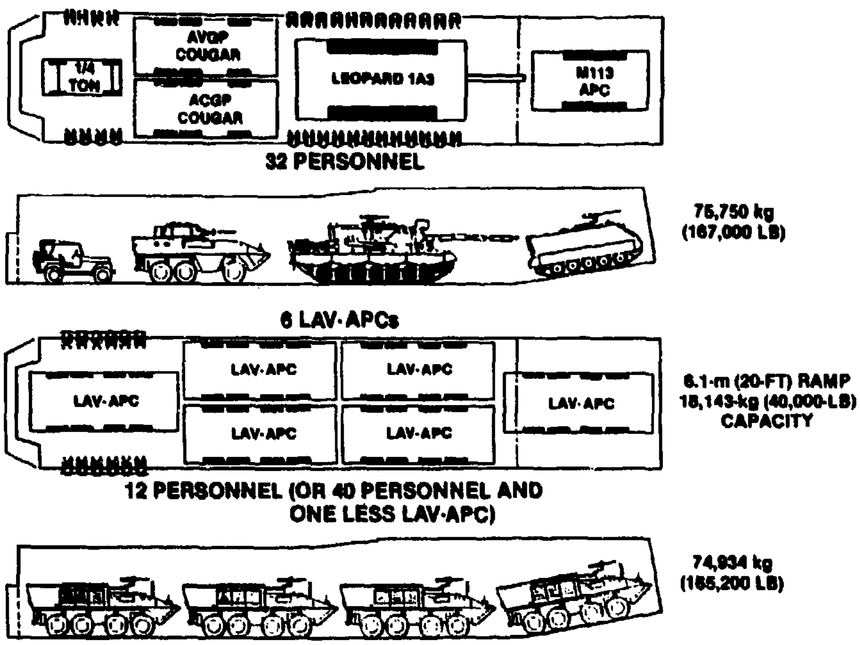


FIGURE 9. HEAVY LOADS INTO 823-m (2,700-FT) FIELD
(556-km RADIUS, SL/32°C; 300-NM RADIUS, SL/90°F)

The large volume of vehicles that can be loaded in the C-17 results from its large cargo ramp and doors and the fact that more than 18,000 kilograms can be carried on the ramp. The height of the cargo compartment is sufficient for tall items such as helicopters (Figure 11). Helicopter units can be moved in a single lift.

The cargo compartment floor of the C-17 is the largely responsible for its versatility (Figure 12). The aerial delivery rails that run down the center of the cargo compartment accommodate 11 of the standard 463L cargo pallets which are 2.74 meters

- **19 C-17 LOADS (AVG PAYLOAD 64,146 kg/141,473 LB)**
- **CAPACITY TO MOVE AUGMENTATION FORCES AND ADDITIONAL SUPPORT ALONG WITH THE TANKS**

MAJOR WEAPONS AND EQUIPMENT TOTAL WEIGHT = 1,218,782 kg/1,344 TONS			
TANK COMPANY		AUGMENTATION & SUPPORT	
80 PERSONNEL		86 PERSONNEL	
LEOPARD TANK	18	RECOVERY VEHICLE	1
LIGHT TRUCK	2	LIGHT TRUCK	8
MEDIUM TRUCK	1	MEDIUM TRUCK	25
		10-TON TRUCK	2

FIGURE 10. RESULTS OF TANK COMPANY LOADING ANALYSIS

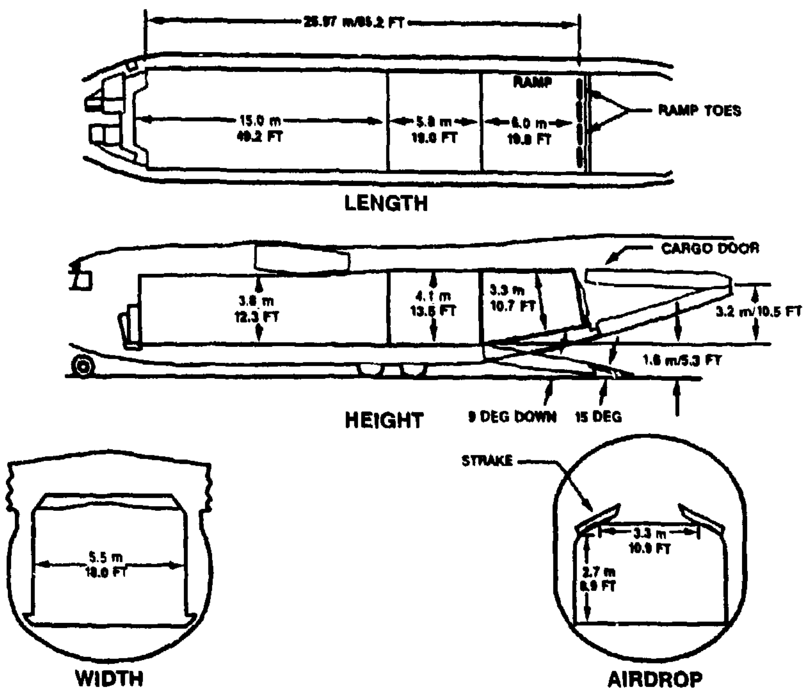


FIGURE 11. CARGO COMPARTMENT DIMENSIONS

wide. There is ample room and seating for 54 personnel when these pallets are loaded. By turning the pallets sideways on the ramp rollers, two rows of pallets can be loaded into the logistics rails. These pallets are 2.23 meters wide in this position, and 18 can be loaded. If only one row is used for pallets, there is still sufficient space for vehicles in the remaining space.

The versatility of the cargo system is enhanced by the fact that the compartment can be reconfigured by a single loadmaster while the aircraft is either in-flight or on the ground. Reversible roller trays can be flipped over for pallet loads. All conversion items such as centerline seats and litter stanchions are stowed on board. Rigging for personnel airdrop is accomplished by loadmasters, and the probability of successful mission completion is improved by precision-setting the airdrop restraint locks.

The C-17 can also be used to transport patients in litters or seats and download fuel directly from the wing tanks into land force vehicles. Delivery options include the low-altitude parachute extraction system, or LAPES; airdrop of personnel, equipment, and supplies; and combat off-load from either rail system.

AVIONICS

The C-17 cockpit matches the cargo compartment in modernization, versatility, and efficiency. There are only two members of the flight deck crew — a pilot and copilot. Two additional seats are behind the pedestal for an instructor or special

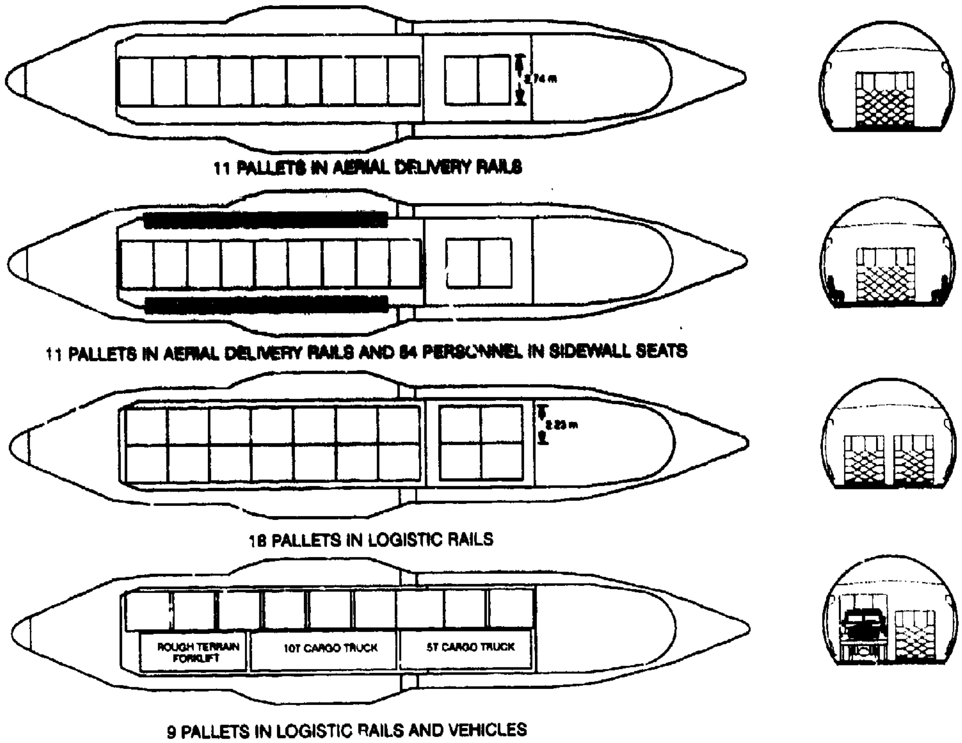


FIGURE 12. CARGO COMPARTMENT CONFIGURATIONS

mission commander, plus bunks and a work area for a second crew. The key features of this cockpit are the two head-up displays, an instrument panel that displays by exception, the four multifunction displays (MFDs) and eight standby indicators, the three redundant mission computers with their four displays, and control sticks rather than yokes (Figure 13).

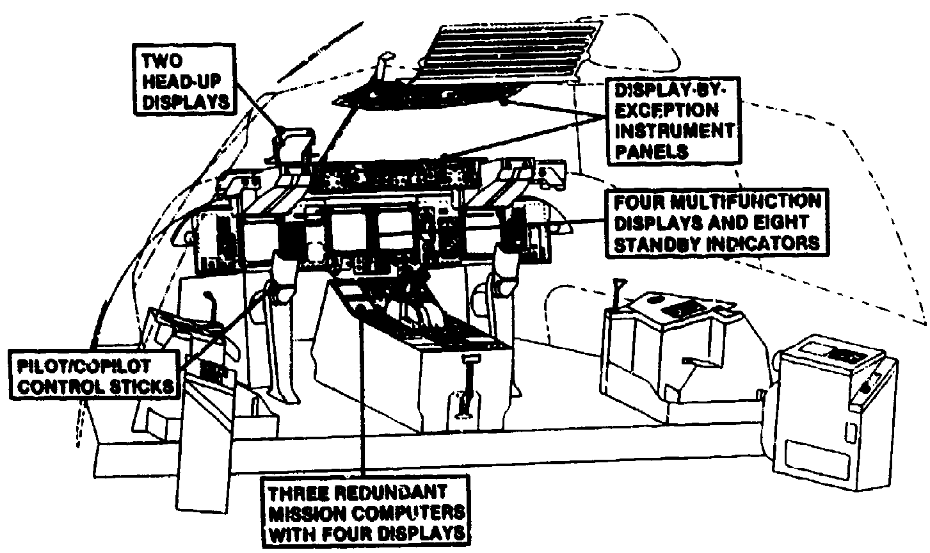


FIGURE 13. THREE-DIMENSIONAL PERSPECTIVE OF C-17 COCKPIT

The pilot can easily view three of the MFDs on the instrument panel (Figure 14). There are five different MFD formats: Primary Flight, which is normally displayed on the co-pilot's dedicated panel; Navigation; Plan Position Indication, such as radar; Engine; and Configuration. Submodes are available for the last four formats. The flight crew can switch formats from one screen to another to best suit its needs. Standby or backup instruments are arranged around the MFDs.

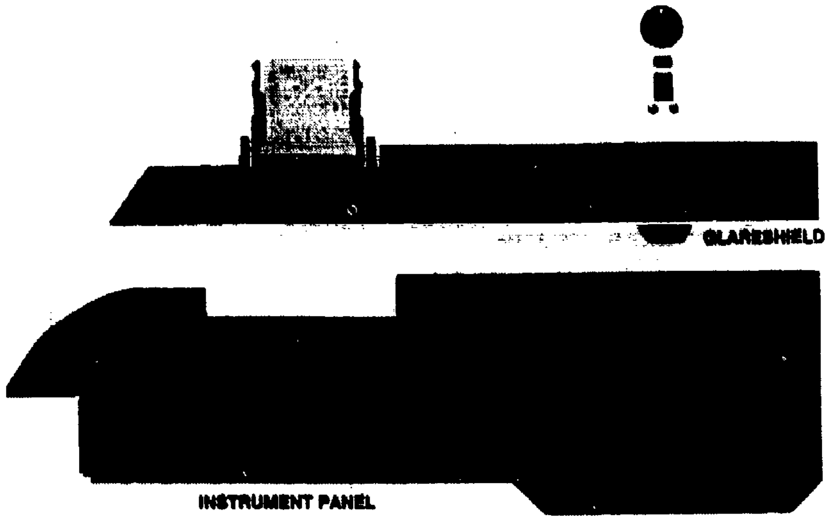


FIGURE 14. PILOT'S GLARESHIELD AND INSTRUMENT PANEL

The pilot's glareshield has a head-up display with primary flight data on it. The glareshield also includes the integrated radio management system and the navigation radios in the communication navigation control. This allows frequencies to be selected by a pilot without lowering his field of vision..

The C-17 employs digital electronic fly-by-wire technology with mechanical backup for flight control. The electronic flight control system monitors onboard commanded configurations and provides parallel autopilot positioning of the control stick for aileron and elevator movement. Automatic functions are: three-axis stability and control augmentation system, autopilot, flight director, autothrottle control, and automatic flight control system.

Full-authority quadruplex configuration is maintained in the "electronic control" mode as long as two or more of the four flight control computers (FCC) are operational. In the event three of the four FCCs are lost, the hydraulic-mechanical backup system is engaged, providing a "get home" capability.

The integrated systems control panels are located above the crew in the C-17 cockpit. The switches on these panels for fuel, hydraulics, pneumatics, and electric power are "set and forget" controls. Levels are automatically monitored by the onboard computers, and in the event of abnormal consumption, the crew is alerted by the appropriate indicator illuminating.

The overhead panel also contains the C-17 watchdogs: the warning and caution system, and the central aural warning system. Any abnormal condition brings tone and voice message alerts to the crew and a written message on the billboard as to the cause. The ground proximity warning system, which is also in the overhead panel, receives input from the flap and gear positions, radar altitude, barometric altitude, and glideslope deviation. It has five operational modes which can be tailored to the special requirements of a military mission.

The aircraft recording system includes four recorders, each with a different function, rate, and format. The cockpit voice recorder provides a 30-minute crash-protected record of the crew voice communications. The other three recorders receive inputs from the aircraft and propulsion data management computer. The crash data recorder provides a 25-hour record of digital information. The aircraft structural integrity program recorder provides onboard recordings for the load environmental spectra survey and individual aircraft history. And the airborne integrated data system quick access recorder compiles engine data on tape cassettes. It can also be used to record any of the crash data parameters collected for maintenance actions.

The control pedestal between the pilots contains the throttle levers, radio controls for presetting up to 20 frequencies, and the mission computer keyboards. The three redundant mission computers continuously cross-check each other for accuracy. They can be accessed manually by two keyboards, while flight planning data can be entered from outside sources with a laptop computer.

Information from the aircraft computers is shown on the two head-up, four multifunction, and four mission computer displays. The mission computer displays are on the forward pedestal. These displays have touch-button controls with "pages" of information on frequencies, routes, airfields, reference points, and navigational aids.

The navigation system enables the two-pilot crew to conduct all airlift missions. It provides all-weather, worldwide navigation capability for short-range, long-range over land and water, and rendezvous and airdrop/airland missions. The system is composed of four inertial reference units, the mission computers, the Global Positioning System, weather radar, conventional navigation radios for very high frequency (VHF) omnidirectional range (VOR) and distance measuring equipment (DME), station-keeping equipment, and two combined altitude radar altimeters.

SURVIVABILITY

The C-17 is designed for routine operations in the severe environments of the forward areas where land force commanders need airlift support (Figure 15). Aircrews can routinely train for low-level operations because the structure of the C-17 is designed for these maneuvers (Figure 16). Because it has a short-field takeoff and landing capability, the C-17 can be diverted to adjacent airfields when the desired airfield is unsuitable or is not available. At gross weights of 181,439 kilograms, the C-17 has a 3-g capability at 350 knots. Since the C-17 can carry four times the payload of a C-130, only one aircraft need make a flight for such a payload, exposing only three aircrew members instead of 20 and eliminating the risk of a succeeding aircraft being engaged by an alerted enemy. The C-17 also spends minimal time in the most vulnerable area — the forward austere airfield — as it is designed for drive-off equipment or the "combat off-load" of pallets, eliminating the need for material handling equipment. The other design features of the C-17 such as the onboard inert gas generating system (OBIGGS) also support the utility of the C-17 in austere airfields.

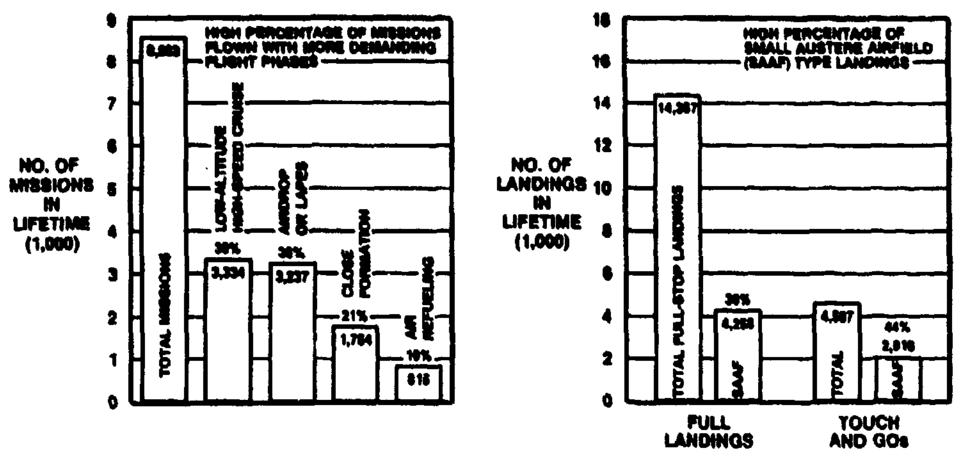


FIGURE 15. DESIGN REQUIREMENTS FOR C-17 LIFETIME OPERATIONS

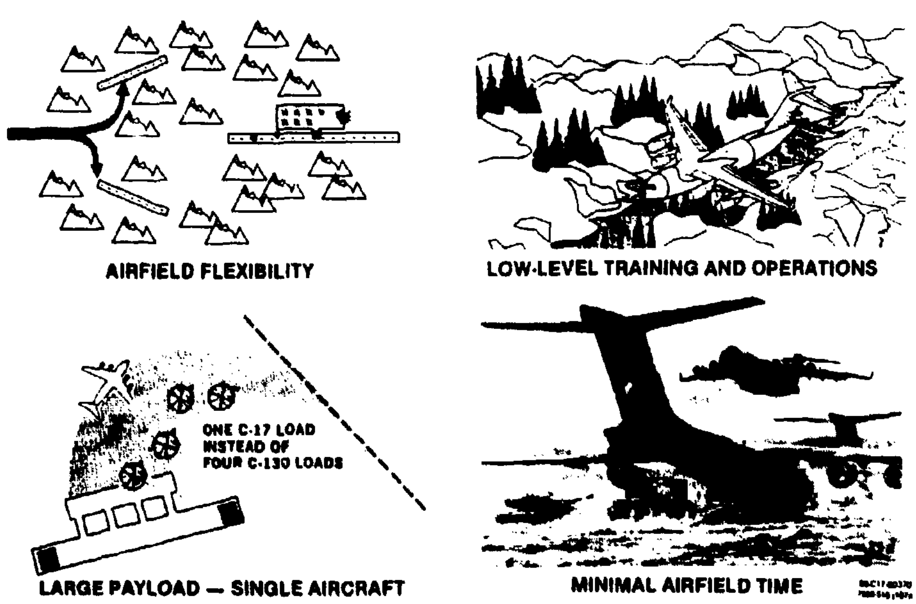


FIGURE 16. DESIGN REQUIREMENTS FOR BATTLEFIELD SURVIVABILITY

The C-17 is less vulnerable than older aircraft because it has a fuel system with compartmented fuel tanks that are inerted by OBIGGS. There are two boost pumps per tank and any one pump can supply two engines. It has four independent hydraulic systems and 12 pumps, and the plane can continue to fly with only one hydraulic system and one pump operating. The structure has a damage-tolerant design with multiple load paths. The propulsion systems are well separated and shielded. There are four engine generators and one auxiliary power unit (APU) generator — any two will fully power all systems and the battery alone will power all essential systems for 30 minutes. The quad redundant flight controls have mechanical backup.

The Air Force is evaluating options for equipping a selected number of C-17 aircraft with defensive systems. Space is provided on the pedestal for controls, and space, weight, and power requirements have been considered for a nominal system. The systems under consideration include missile warning receivers and flare dispensing equipment.

MAINTAINABILITY

In addition to its performance capabilities, the most important aspect of the C-17 is its designed-in maintainability features to ensure lowest possible life-cycle costs. Maintainability features aimed at sustaining a high availability rate and providing ease of maintenances include 227 access panels and doors, an integral ladder in the vertical tail, and an underfloor passageway. Easily accessible servicing point locations make it possible to meet quick turnaround requirements. Maintenance problems are identified by a comprehensive centrally reported built-in-test system. Efforts are under way to automate technical and logistics data for ease of management through the computer-aided acquisition and logistics support system. Additionally, the C-17 does not require a jack for the main landing gear as the aircraft can jack itself for tire changes. OBIGGS eliminates the need for nitrogen replenishments. The designed-in maintainability features in the C-17 allow rapid replacement of maintenance-significant items at the forward or deployed base environment with a minimum of support equipment. The C-17 is expected to operate at a significantly lower number of maintenance man-hours per flight hour when compared to comparable aircraft in the Air Force inventory. The overall design and built-in features of the C-17 ensure the lowest possible operation and support costs for its entire life-cycle.

FLEXIBILITY

Derivative applications that are not part of the Air Force C-17 contract are under review at McDonnell Douglas. Some of these are: a combination transport/tanker that incorporates hose and drogue pods from the existing hard points on the wing, a special mission variant that incorporates a double deck and can be used for medical, communications and control, or search and rescue missions.

The Air Force plans to buy 120 aircraft through the year 1997. The first flight is planned for 1991, with a 12-aircraft squadron operational in 1993.

FIMA AND EUROFLAG : PROGRESS IN MEETING MILITARY AIRLIFT AND FLA REQUIREMENTS FOR THE 21ST CENTURY

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SUMMARY

The paper reviews progress made initially by the Future International Military Airlifter (FIMA) Group and, since 1989, by its successor the European Future Large Aircraft Group (EUROFLAG), in studying the potential for development of a collaborative programme to satisfy airlift requirements for the 21st century. EUROFLAG studies indicate that future military transport and other FLA designs based on mid-1990s, modern but proven technology standards, can provide a greatly enhanced airlift capability at significantly lower fleet life cycle costs and with major manpower savings compared with aircraft in service today. These attributes are important in a world climate of shrinking defence budgets, growing manpower shortages and defence scenario uncertainties. European or transatlantic collaboration to develop and manufacture such aircraft is seen as the most economical way for air forces to obtain the operational capability required at the lowest cost. (25)

INTRODUCTION

* Military aircraft, * Airlift operations,

In December 1982, four companies, Aerospatiale, British Aerospace, Lockheed and Messerschmitt-Bolkow-Blohm (now renamed Deutsche Airbus), signed a Memorandum of Understanding (MOU) which provided a springboard for joint studies into future military transport needs, possible solutions and collaboration opportunities. In 1987, the group was expanded to six companies when it was joined by Aeritalia and CASA. In 1989, Lockheed left the group by mutual agreement, and the five European Companies signed a new MOU under the title European Future Large Aircraft Group (EUROFLAG). The work reviewed in this paper draws on the experience and the results of past studies and focuses on some of the key issues addressed. The companies have concentrated their attention on the needs for transport aircraft in the C-130 Hercules and C160 Transall class - sometimes referred to as medium-airlift - and on similar-sized corollary role aircraft (eg tankers, and LRMPA).

Throughout the paper, reference is made to "Future Large Aircraft" (FLA). This is a generic term used by the FLA Exploratory Group (FLAEG) of the Independent European Programme Group (IEPG) to describe future, medium-size (approx 75-125 tonnes MTOW) transport aircraft, and derivatives intended for tanker, maritime patrol, airborne early warning, electronic reconnaissance or other FLA roles.

THE EUROPEAN INDUSTRIAL GROUP - EUROFLAG

Aeritalia, Aerospatiale, British Aerospace, CASA and Deutsche Airbus are an industrial group with wide experience in military and civil international collaborative projects. It is the Group's intention to form a limited liability company in Rome, Italy. This will strengthen their ability to engage jointly in all activities necessary to achieve a programme for medium-sized military transport aircraft and any derivatives. It will provide a single point of contact between EUROFLAG and other companies and agencies. Whereas, even now, the companies consult and act in unison on all matters concerning the programme, the formation of a single EUROFLAG company and headquarters will further assist collaboration.

The aims of EUROFLAG are to co-operate in requirements definition, engineering, production, customer support and marketing for FLA. The group's task includes the determination of technology readiness, the development of aircraft configuration options, business plans and possible collaboration agreements. EUROFLAG represents the partner companies collectively to third parties. The EUROFLAG organisation is currently at three main levels. At the senior management level there is an Executive Board (EB) consisting of the Managing Directors (or equivalent titles) of the five companies of the group. The EB decides and directs the overall programme strategy and the level of effort. Below that is a EUROFLAG Management Committee (MC) which manages the work programme. Joint Working Groups (WGs) of specialists undertake the day-to-day work on a shared basis. This method of co-operation is economical and works well. Through long-standing co-operation, EUROFLAG partner companies have developed a bond of mutual confidence and understanding. EUROFLAG embraces all the major partners who are also involved in the Airbus programme, and are in the forefront of aerospace design, technology and development, world-wide. Technology and experience of the Airbus A320, A330 and A340 programmes are being applied to and will directly benefit the European FLA project. Additionally, work by EUROFLAG companies on military combat aircraft such as Tornado and EFA will also have application to FLA. Hence, the sum of modern technology experience across a broad range of military and civil programmes in which the EUROFLAG companies are or have been involved, can converge and focus on a European FLA project.

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THE MARKET

Beginning in the late 1990s, about 1250 medium-size military transport aircraft, 200 tankers and 60 maritime reconnaissance aircraft in service in NATO and the rest of the world will become due for retirement and replacement; this excludes Eastern Europe, the USSR and the Peoples Republic of China. In addition, there are some 700 long range maritime patrol aircraft of which 400 are operated by the USN. While the transport market alone could support more than one type world-wide, it would be more economical for Western air forces to agree upon a single transport aircraft design.

FUTURE AIRLIFT MISSION NEEDS

Whether in the context of Alliance or 'out-of-area' operations, in times of threatened hostility or war, a nation's military airlift is likely to be required at short notice to deploy army and air forces rapidly to their required operational areas or forward operating bases. These may be only a few hundreds of miles distant, or several thousand. Deploying forces must take with them their vehicles, artillery, anti-aircraft defence systems, helicopters, stores and ammunition, to provide their mobility and fighting capability. Deployed air force squadrons likewise need all their maintenance personnel, ground support and test equipment, spares, vehicles, ammunition, bombs, missiles, additional drop tanks, etc to be airlifted to deployment bases in the shortest time possible to allow aircraft to become combat ready immediately on arrival. The moving of troops and air force ground-crews themselves is not usually a major airlift problem. The main factor to influence the time required to complete an airlift, is a transport fleet's capacity to carry, firstly, large numbers of vehicles, trailers, towed equipments, containers, cabins, plant and similar equipments, many of which are bulky and low in density; a force of 2500 troops could typically require up to 1000 vehicles, trailers etc, to be airlifted in the initial deployment. Secondly, high tonnages of palletised ammunition; the airlifting of anything from 400 to 3000 tonnes of ammunition and up to 1000 tonnes of stores, is typically required.

Once deployed, ground and air forces must be re-supplied. Casualties (and even prisoners or war) need to be evacuated quickly, and on a regular or daily basis. A shortage of arrival-time slots, congestion, and a lack of cargo handling facilities at forward airfields are common problems in airlift deployment and re-supply operations. Optimisation of the transport aircraft's cargo hold to maximise its payload-carrying, delivery and pick-up capabilities, will be key factors in determining the aircraft's efficiency and cost effectiveness.

Range, too, is important. Too little range may restrict the routes over which the aircraft can operate, or significant payload weights may have to be sacrificed for fuel thus extending the completion time of airlifts. Avoiding the need to refuel at forward operating bases or airstrips can be important where fuel stocks are limited, airfields are congested, fuel bowsers are scarce, or survivability considerations necessitate aircraft remaining on the ground for the shortest time possible. Another consideration is that most air forces cannot afford to operate more than one main military cargo transport aircraft type. Moreover, very large strategic airlifters, such as the C-5B and C-17, have a much greater capacity than air forces outside the USA can, in general, utilise economically in peactime. Hence, the future tactran's range will have to be adequate with a substantial payload, not only to cover the extremities of the NATO area but beyond, to national, out-of-area locations. A future 'tactical' transport is therefore likely to have a payload-range in the order of 2200-2500nm. A long range capability has the added benefits of enabling tactical missions to be flown at low altitude without the need to refuel at forward airstrips. This increases mission rates and reduces vulnerability.

Speed, also, is important. Faster cruising speeds reduce sortie times and crew and passenger fatigue, and more sorties can be flown by each aircraft and crew per day over a given stage length. This reduces airlift completion times and requires fewer aircraft to carry out a particular airlift. This increases operational flexibility within a given fleet size by releasing aircraft to do other concurrently required tasks. Some reduction in crew:aircraft ratio may also be possible without loss of operational capability. Since airlift tasks can be completed in fewer flight hours, maintenance man-hours per airlift task in peacetime will also be reduced.

In addition to air-landed deployment, resupply and recovery operations, there will be a continuing need for military transports to be able to airdrop paratroops, heavy equipments and supplies in large quantities, and accurately, including at night. Forces may become largely or wholly dependent on resupply or recovery, by air. However, the increased numbers and lethality of hand-held and mobile anti-aircraft weapons and small arms, common in armies everywhere including the third world, demand that greater attention be given to increasing the survivability of future tactical transport aircraft which at times will have to be flown in risky or hostile areas. Major survivability improvements can be built into a totally new tactran by damage-tolerant design of the structure and systems. Threat avoidance can be increased by designing and equipping the aircraft to manoeuvre and fly safely and faster than today, at low level, including at night and in all weather, and by providing it with defensive systems and crew protection. Modern engines can provide an FLA tactran with a radius-of-action of 700-1000nm at 200 ft with typical tactical payloads. In general, therefore, there is both the likely need and the capability to design a new generation FLA with significantly greater levels of survivability and reduced vulnerability compared with current tactical transports and fleets of adapted civil aircraft.

RATIONALISATION OF FUTURE LARGE AIRCRAFT FLEETS

The draft Outline European Staff Target (OEST) for "Future Large Aircraft", prepared jointly by the Ministries of Defence of Belgium, France, West Germany, Italy, Spain, Turkey and the United Kingdom, was issued in April 1988. The OEST covers requirements for a tactical transport (Tactran) and a tanker variant. It recognises the advantages and potential for the development from a transport aircraft, of FLA derivatives for other large aircraft roles (eg tanker and LRMP). It acknowledges that some interchange between these roles could also be possible; for example, the re-roling of tactrans for tanking. The FLA fleet rationalisation concept, which has the potential for reducing fleet life cycle cost (LCC), is stated as an objective in NATO Euro Longterm Air Sub-Group Sub-Concept Paper ELT-72 dated 29 September 1986 - Rationalisation of the NATO Fleet of Large Aircraft. EUROFLAG, too, recognises the benefits of fleet rationalisation. While design-driving requirements for the transport aircraft must be over-riding, resultant basic designs can be examined for their suitability, with minor or major modifications, as corollary role derivatives or variants. If certain changes to the basic aircraft or its performance can improve its potential for other roles without significant detriment to its cost-effectiveness as a military airlifter, such changes can and should be considered early in the design phase. The logistics, operational, training and LCC advantages of reducing the numbers of types of aircraft (and engines) within air forces are self-evident. Preliminary indications within EUROFLAG are that an efficient tanker variant could be derived from a modern FLA transport; this could take the form of a 2 or 3 point tanker/transport, or a specialised 3 or 4 point drogue and boom tanker, with a fuel transfer capability of 40000-50000 Kg (88000-110000 lb) at 300-450 nm radius-of-action. Such an aircraft could operate from relatively small airfields (and even semi-prepared airstrips) and, being intended as a military aircraft, would have a high level of survivability built into the design compared with present-day tankers. EUROFLAG will continue to examine possible future tactran designs for their suitability for corollary roles, especially air-to-air refuelling (AAR) tankers and long range maritime patrol (LRMP).

SATISFYING FUTURE OPERATIONAL REQUIREMENTS - EUROPEAN FLA

A number of key characteristics for a future tactical transport have been identified by European air forces in the FLA OEST, and some of these are briefly mentioned. The aircraft is required to be simple and rugged incorporating modern, proven technology of the mid 1990s. It must have a greater payload and cargo hold capacity than the C-130 and C160. An enhanced fleet airlift capability is required at lower fleet LCC. The aircraft should incorporate substantial improvements in reliability, maintainability and availability, and major savings in maintenance manpower. Improved rough-field performance and ground manoeuvrability are required, with the ability to carry a 20-25 tonne payload into CBR6 airstrips 760-900m in length. A high cruise speed is called for, typically 400-450 KTAS at 30000 to 36000 ft, and 300-350 KTAS at low level; the aircraft should be capable of all-weather operation, day and night. Threat detection and avoidance with improved manoeuvrability (including a 3g manoeuvre factor), crew protection and defensive systems, are also required. Fly-by-wire or fly-by-light control systems, and a 2-man 'glass' cockpit, are expected.

The challenge is to find the best compromise for an efficient and affordable solution. Some of Europe's key requirements (Fig 1-6), are somewhat separated. However, these are 'indicative' requirements, and in some cases nations have already stipulated a bracket around which a compromise can be found. Some relaxation of one or two of the more demanding requirements is already known to be under consideration. Others may represent little more than a provisional 'wish list' since cost-versus-capability trade-offs have not been carried out and the comparative costs are not known by air forces; this is work that EUROFLAG has advocated. However, the general pattern is clear. Air forces need an aircraft with a design payload of 20 to 25 tonnes. This implies a required increase in actual payload-carrying capability of between 40 and 75 percent compared with that typically achieved by the C-130 and C160 with average density payloads. A 20-25 tonne payload equates approximately to a carrying-capability of 8-9 pallets (88 x 108 in) plus 35 to 55 troops. Increased cabin height and an unobstructed cross-section are needed to accommodate large trucks and medium helicopters of the Super Puma, PAH-2, Black Hawk, Apache class, without removal of the gearbox etc. All air forces are asking for a significantly wider floor than the C-130 and C160; between 3.66m (144 in) and 4.0m (157 in) is most commonly required, compared with the current 3.13m (123 in) floor width.

The advantages of a wider floor are illustrated, first, at Fig 7. On the left is shown the cross-section of current aircraft. Only if pallets are loaded in the 2.24m (88 in) configuration can passengers be accommodated in side-wall seating.

Similarly, common light military vehicles of the UMM490, FIAT 1107, VW Iltis, Landrover, VLTT size, and their associated trailers, can mostly be loaded only in a single row, resulting in low payloads. These and other vehicles are commonly required to be deployed in large numbers; using today's aircraft they typically constitute 25-40 percent of the total sorties required for major army deployments. The ability to double-row light vehicles and towed equipments, and to seat troops on both sides of pallets loaded in the 2.74m (108 in) configuraton, can achieve major increases in payload uplift per sortie. This will significantly reduce airlift completion times, cut the numbers of sorties required, reduce demands on and congestion at forward airfields, and ameliorate airlift concurrency deficiencies acknowledged in the OEST. The percentage of light vehicle types which can typically be loaded side-by-side and the percentage gain in payload, on various floor widths, are shown at Fig 8.

European air forces have not yet agreed a common, design payload-range or radius of action for the FLA tactran. Instead, they have individually specified certain high priority mission profiles which they would wish to be able to fly unrefuelled. As the payload-range graph at Figure 9 shows, some are more demanding than others; moreover, the payload or range requirements of some of the longer range missions are expected to be relaxed. Ultimately, all nations' payload range and other key requirements are likely to be sufficiently close to be met efficiently by a single aircraft design. In a transport aircraft, few performance requirements can be regarded as 'absolute', so that some compromise is almost always possible without major detrimental effects.

EUROFLAG DESIGN CONCEPTS

A range of different design concepts have been examined. In 1982, the assumed spread of performance requirements was more widely separated than today. Because of this, early conceptual design studies began with a pair of aircraft: a twin-engined turbofan transport and a larger, more capable 4-engine turbofan aircraft. This dual solution was aimed at satisfying both the least and the most demanding ends of the spectrum; it resulted in almost no commonality between the two aircraft. Companies then examined modular solutions with as much commonality as possible with the aim of defining a more economical programme. Combinations of aircraft with 2, 3 and 4 turbofan engines, and 4 turboprops or propfans with single or counter-rotating propellers, were all studied and their likely cost compared. A later approach was a two-aircraft solution with a common fuselage and common external geometry, but different structural strengths; these became known as the FIMA D4P Base and Max, the Max version having a longer range.

The message derived from this work is that the most cost-effective solution, whether it be 2 or 4-engined, is for a programme based on a single aircraft design (a 3-engined aircraft is not favoured, for design, logistics and other reasons). Even though some nations may consider that a chosen common aircraft has more capability than they require, while others may feel it falls a little short of their optimum needs, analysis will show that fleet life cycle cost savings due to fewer numbers of parts, bigger production runs and lower non-recurring costs will outweigh the detrimental effect of any excess or shortfall in the capability of an individual aircraft design. What has to be established is where on the fleet LCC versus capability curve the optimum solution lies. This can best be determined by specifically targetted prefeasibility trade-off studies tasked upon EUROFLAG by the IEPG Future Large Aircraft Exploratory Group (FLAEG) or NAFAG Air Group 1. To meet the FLA development schedule contained in the draft OEST, the commencement of such studies is already overdue.

AIRLIFT IMPROVEMENTS ATTAINABLE BY A EUROPEAN FLA

Paper No 14 described some of the possible alternative FLA configurations. Attention was drawn to the major impact of advances in engine development over the 30-40 years technology gap since current, basic transport aircraft designs were fixed. Three-view drawings of possible FLA tactrans are shown in Figures 10, 11 and 12. MTOW will probably be between 80-110 tonnes with a wing area of 145-200m^2. The span will be generally similar to the C-130 and C160. A major difference will be in the fuselage diameter, about 25 percent larger than the Hercules and Transall. Modern engines will allow an economical cruise speed of M=0.72 although higher and lower speeds are being considered. Cruise speed at low level is expected to be 300-350 KTAS. To meet military requirements, the design payload range is likely to be 2000-2500nm.

Assuming a design payload of 20-25 tonnes, a floor width between 3.66m (144in) and 4.0m (157 in) and an overall floor and ramp length of between 20m (65 ft) and 22m (72 ft), EUROFLAG modelling indicates that 50-100 percent improvement in airlift capability can be expected for this general size of aircraft compared with the C-130 and C160. Studies of realistic military airlifts show that payload factors of 80-95 percent will generally be attainable, even when carrying such loads as soft skinned vehicles or freight pallets with passengers/troops. A 3.0g manoeuvre factor at 20 to 25 tonnes payload, required by European air forces, will provide improved tactical manoeuvrability and survivability at low level; it can also safely allow fuel to be traded for above-normal gross payloads (eg to carry extra ammunition) over less than maximum design ranges without exceeding the normal MTOW.

The European FLA is required to supersede and improve upon the C-130 and C160. Airlift studies carried out by EUROFLAG using the British Aerospace Automated Transport Loading Assessment System (ATLAS) therefore have compared the numbers of sorties required by prospective C-130J and FLA aircraft to complete typical major airlifts. The results of one such study are shown in Fig 13. With similar numbers of aircraft, a baseline European FLA with a 25 tonne (55000 lb) design payload and an 87m² floor can complete the specified airlifts in about 40 percent fewer sorties and well under half the time compared with a C-130H or J fleet. The expected reduction in sorties comes from an 85 percent increase in floor area, and an 80 percent higher mean achieved payload per sortie. The assessed mean payload factor (payload offered/payload actually carried) over these airlifts is 0.72 for the C-130 and 0.87 for the European FLA. The shortening of the elapsed time for the European FLA to complete the airlift is due to 40 percent fewer sorties, about 100 knots higher cruise speed, and an expected 90 percent Full Mission Capable (MC) availability for a modern FLA, compared with 78 percent assumed for the C130. In general terms a EUROFLAG FLA should have a 50-100 percent greater airlift capability than the C-130. Superiority over the C160 is even greater.

EXPECTED SAVINGS THROUGH IMPROVED R & M

According to published figures, the current USAF mixed fleet of C-130 E and H models averages 23.8 MMH/FH. Other sources quote the C-130H at 21 MMH/FH. Paper No 14 covered R&M expectations for a European FLA in some detail; it can be seen that an 8-fold improvement in MTBM and about a 70 percent reduction in MMH/FH can be expected in a new generation airlifter compared with the C-130. This assumption is based on established in-service experience of Airbus and other modern aircraft, with allowances made for size, different military practices and lower annual flight hours. Improved R & M would allow reductions of about 70 percent in air force transport fleet maintenance effort and concomitant reductions in manpower. This will be an important saving in a climate of defence budget stringency and increasing skilled manpower shortages exacerbated by adverse demographic trends. Similar reductions in MMH/FH, costs and manpower could be expected for an FLA tanker and other corollary role variants. While it is not within the scope of this paper to discuss precise costs, on the basis of comparable fleet airlift capability it is estimated that a fleet of modern European FLA tactrans would show savings of 40-50 percent in fleet LCC over a 30-year period, compared with the C-130H (depending upon the particular design selected and the analysis criteria used).

PROSPECTS FOR AN FLA PROGRAMME

In July 1988, the FIMA Group proposed a programme for the development and introduction into service of a European FLA and in May 1989, proposals were made for Prefeasiblity Studies (PFS). Experience, and many official reports, indicate that too little effort devoted to relatively low-cost but fundamentally important studies at the outset of a programme tends to lead to programme cost over-runs and delays; avoidable expenditure early in the programme escalates LCC unnecessarily and cannot be recovered later.

An encouraging start was made by the IEPG in 1985, culminating in the completion of the draft FLA Tactran and Tanker OEST in July 1987. The decision by the NATO Conference of National Armament Directors (CNAD) in late 1989, to initiate action within the NATO Air Forces Armament Group (NAFAG - Air Group 1) to consider the replacement of medium-lift and heavy-lift transport aircraft over the next 20 years, is also welcome. In the USA, as reported in Paper No 2, a draft Statement of Operational Need (SON) for an Advanced Theatre Transport (ATT), a successor to the long-serving C-130, is apparently on circulation within the USAF and US industry. There may well be a high degree of commonality of requirements between USAF and European air forces; if so, it will make economic sense for both to be satisfied by a common transatlantic collaborative programme in which EUROFLAG is linked to a US company.

The IEPG is expected shortly to initiate PFS trade-off studies by industry to harmonise European requirements. By the time this task is completed, Advanced Theater Transport Mission Analysis (ATTMA) studies, which have been underway in the USA for several years, should have been finished and the feasibility of drawing together requirements on both sides of the Atlantic into a single programme can then be addressed. The evidence so far available is that either European or European-US programmes are viable.

CONCLUSION

Some 800 NATO tactical transports and 140 tankers are expected to be retired from service and to need replacement between 1998 and 2015. This will provide a unique opportunity to bridge a 30-40 year technology gap by bringing into service new generation FLA fleets which can provide savings in operating, support and life cycle costs. Substantial improvements will be forthcoming in airlift capability and aircraft performance, reliability, maintainability and availability. These can lead to a 70 percent reduction in maintenance effort allowing major cuts to be made in the numbers of military maintenance and back-up personnel. Compared with today's fleets, between 50 and 100 percent improvement in payload uplift capability, 25-35 percent higher cruise speed, about a 15-20 percent improvement in the Mission Capable (availability) rate, and the increased survivability of a new generation FLA, can eliminate current short-falls in airlift without any increases in fleet numbers and at significantly reduced fleet LCC for a given fleet airlift capability. This improvement in fleet life-cycle cost effectiveness is estimated to be in the order of 40-50 percent. European FLA-based derivative tankers and other variants, including LRMPA, can also meet future force requirements at reduced fleet life-cycle and manpower costs, and achieve other economies through fleet rationalisation. Even allowing for some reduction in fleet numbers from today, but without any loss in fleet airlift capability, a European or transatlantic collaborative FLA programme would be 'low risk' and would provide significant long-term fleet LCC savings.

ACKNOWLEDGEMENT

This paper was prepared at British Aerospace with the co-operation of colleagues at the other EUROFLAG partner companies, Aeritalia, Aerospatiale, CASA and Deutsche Airbus. The author wishes to express his gratitude for their valuable assistance.

Figures

APRIL 1990

OEST REQUIREMENTS

FIGURE 1

MAXIMUM PAYLOAD (t)

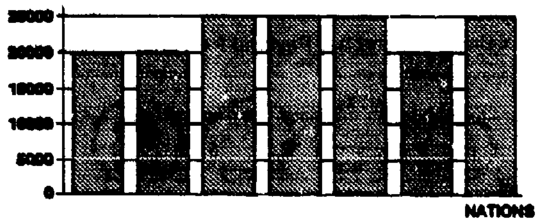


FIGURE 2

g-LOAD

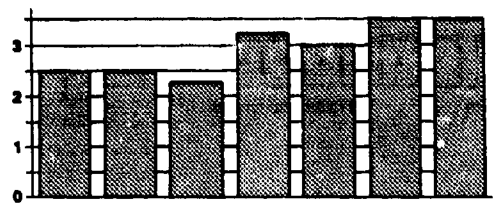


FIGURE 3

CRUISE SPEED (KTAS)

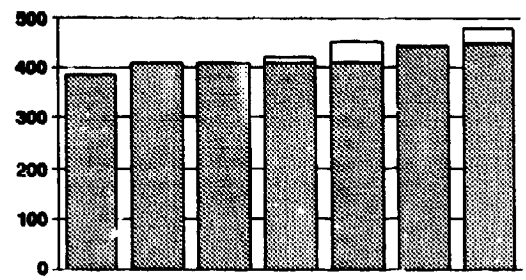


FIGURE 4

TACTICAL FIELD LENGTH (ft)

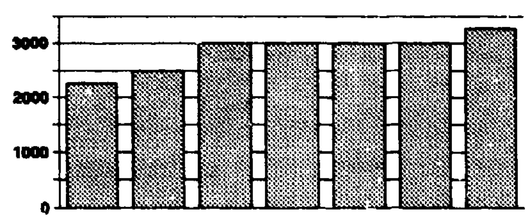


FIGURE 5

FLOOR WIDTH (m)

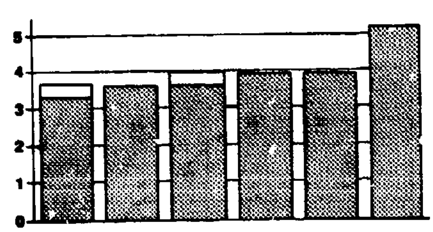


FIGURE 6

NUMBER OF PALLETS

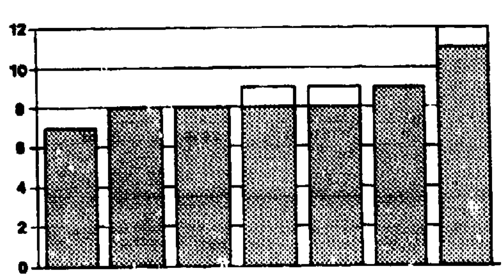


FIGURE 7 **Optimisation of Cargo Hold**

X-Section, Length & Payload for Vehicles, Equipment, Troops & Pallets

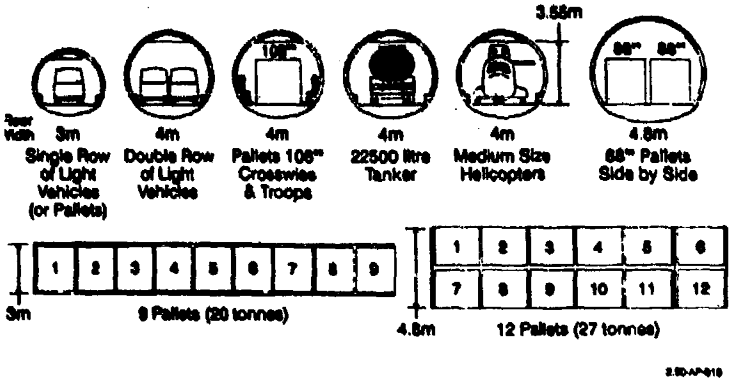


FIGURE 8 **Vehicle Loads**

The effect of floor width on numbers of vehicles, trailers, etc. carried, and on payload factor

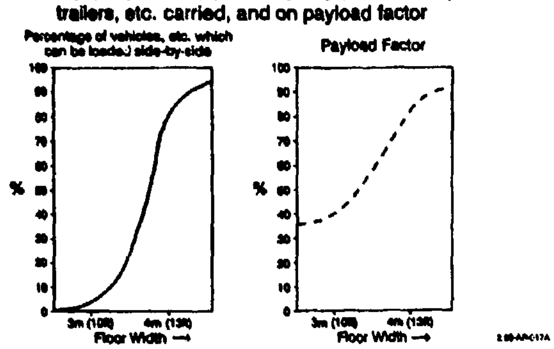


FIGURE 9 **PAYLOAD RANGE**

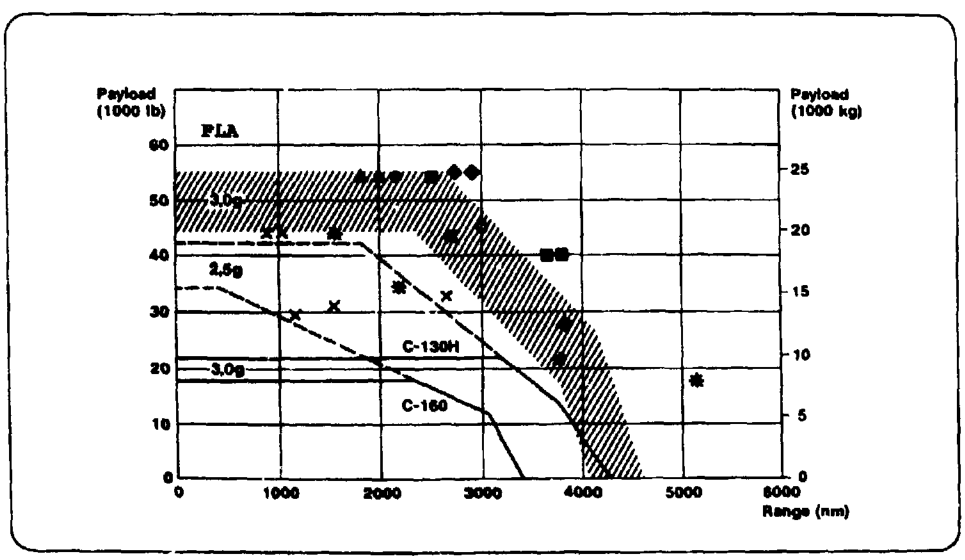


FIGURE 10

CONFIGURATION STUDIES FLA

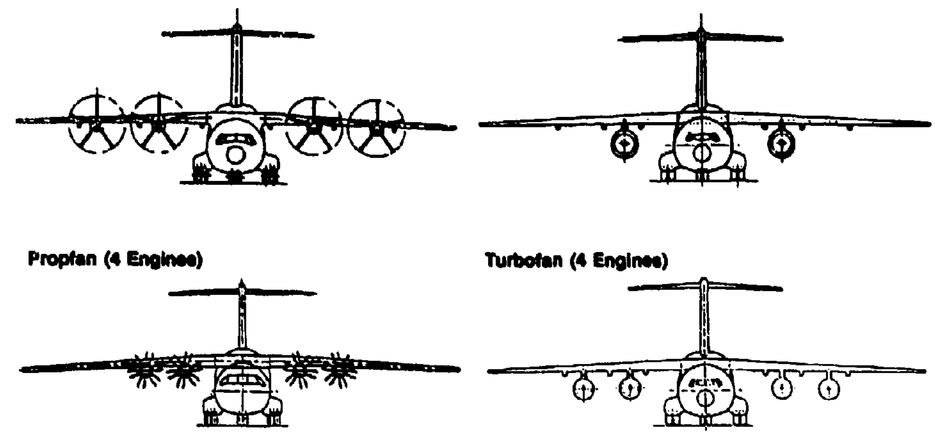
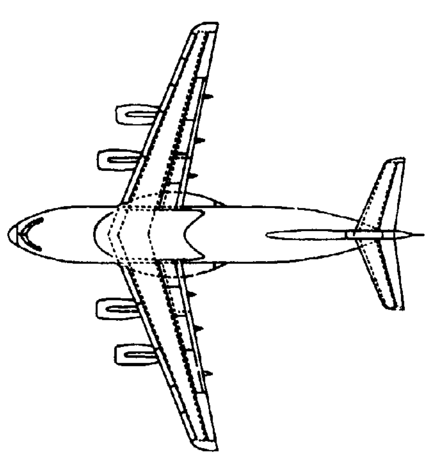
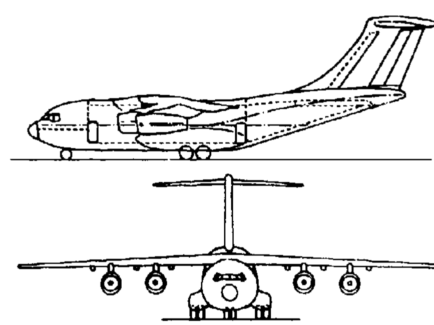


FIGURE 11

MAIN CHARACTERISTICS

TURBOFAN SOLUTION



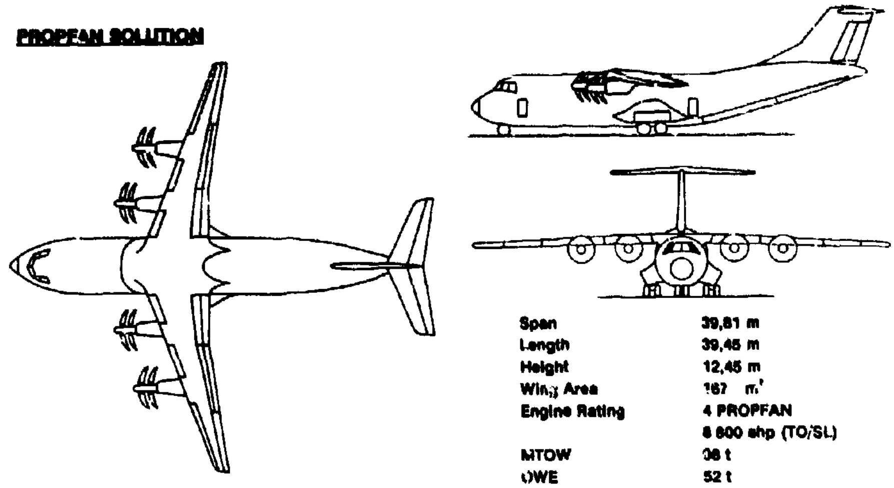


Span	42,70 m
Length	40,30 m
Height	13,30 m
Wing Area	190 m^2
Engine Rating	4 TURBOFAN
	18.000 lb (TO/SL)
MTOW	111 t
OWE	56 t
Payload (3.0g)	25 t

FIGURE 12

MAIN CHARACTERISTICS

PROPFAN SOLUTION



Span	39,81 m
Length	39,45 m
Height	12,45 m
Wing Area	167 m^2
Engine Rating	4 PROPFAN
	8 800 shp (TO/SL)
MTOW	98 t
OWE	52 t
Payload (3.0g)	25 t

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FIGURE 13

AIRLIFT COMPARISON

	CONCURRENT AIRLIFT OPERATIONS (Mission Example)		TIME TO COMPLETE C-130J	FLA
	Assumed Fleet Size		65 ac	65 ac
	Mission Capable Availability Rate		78 %	90 %
• AIRLIFT 1	2350 nm Range 2500 Troops 400 tonnes Stores 1000 Vehicles, Towed Equipment	(D-Day start) 3000 tonnes Ammunition 17 Helicopters	11 days	4 days
• AIRLIFT 2	810 nm Radius of Action 600 Troops Paradrop 1400 Troops Airland 200 tonnes Ammunition + Stores Additional from D-Day + 4 start: 100 tonnes Daily Re-supply	(D-Day + 3 start) 150 Vehicles, Towed Equipment	10,0 hours	3,0 hours
• AIRLIFT 3	600 nm Radius of Action 500 tonnes Ammunition + Stores Daily	(D-Day start)	8 ac/day	5 ac/day
• AIRLIFT 4	2350 nm Range Spare Airlift Capacity for Daily Re-Supply of Ammunition, Stores, Casualties etc.	(D-Day + 4 onwards)	NIL until D+11	2000 tonnes daily

TM 26A03/44

V-22 OPERATIONAL CAPABILITIES

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ABSTRACT

This paper describes the operational capabilities of the V-22 Osprey, the world's first operational tiltrotor aircraft. The designed-in capabilities of the V-22, plus its performance characteristics, provide a multi-mission aircraft that will improve the capability of all service forces well into the 21st century. Key elements in providing a broad operational capability are shipboard compatibility, payload-range, maneuverability, high speed capability with an external load, reduced vulnerability, and "glass cockpit" integrated avionics for reduced pilot workload during day and night missions.

BACKGROUND

The V-22 Osprey tiltrotor is a revolutionary new aircraft being developed by a Bell-Boeing joint venture to provide a multi-service, multi-mission aircraft for the U.S. Department of Defense. Full scale development was initiated in 1985 and led to a successful first flight on March 19, 1989. See Figures 1 and 2. Initial envelope expansion was completed in December 1989 and the objective of obtaining 250 kts in airplane mode was accomplished. Full envelope expansion is now under way and will be completed in 1992 with a Government Operational Evaluation (OPEVAL) of two of the flight test aircraft.

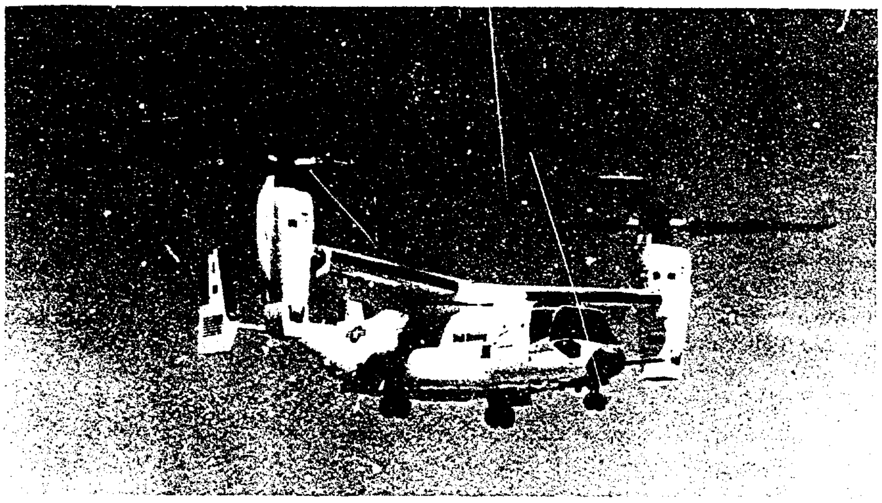

Figure 1. V-22 In VTOL Mode

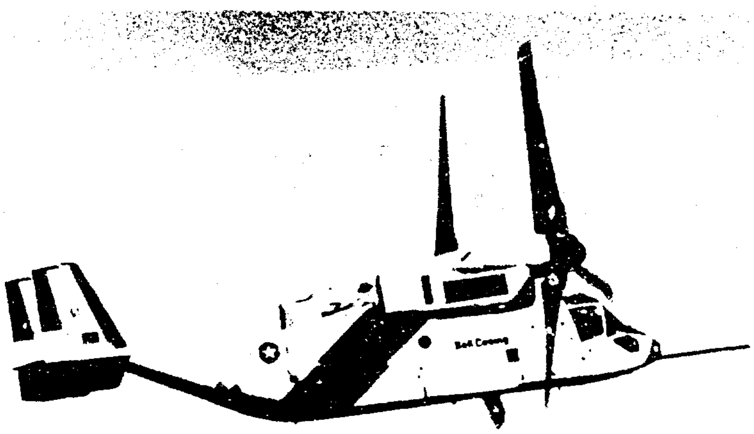

Figure 2. V-22 In Airplane Mode

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AIRCRAFT DESCRIPTION

The key to the broad spectrum of capabilities offered by the Osprey is the unique combination of the hover capability of a helicopter plus the fast forward flight capability of a fixed wing airplane. As shown in Figure 3, the tiltrotor concept provides this dual capability by tilting the wing tip nacelles. In hover with the nacelles vertical, the rotors provide all the lift and as the nacelles are tilted forward, the rotors both lift and propel the aircraft. In airplane mode, the nacelles are horizontal and the rotors only propel the aircraft as the wing provides all the lift.

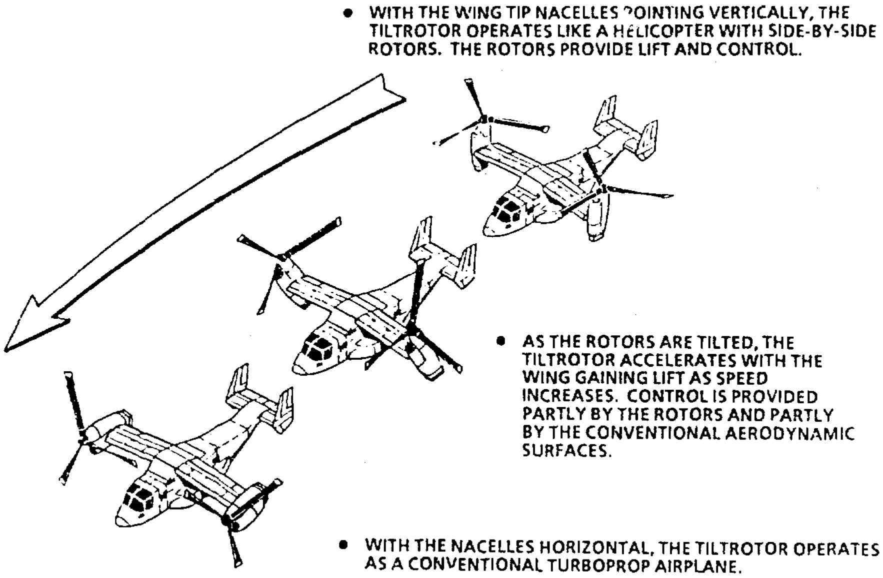

Figure 3. Tiltrotor Conversion

The overall dimensions of the V-22 are shown in Figure 4. Each rotor consists of three highly twisted rotor blades of composite structure. The rotor mechanical control system has standard helicopter controls of collective and cyclic pitch. This is shown in Figure 5 along with the nacelle housed engine and transmission. Each proprotor is driven directly by an Allison T406-AD-400 engine, rated at 6150 shp, through a proprotor gear box. An interconnect drive shaft located along the aft portion of the wing torque box allows one engine to drive both rotors, as shown in Figure 6, so that continued safe flight can be accomplished on one engine.

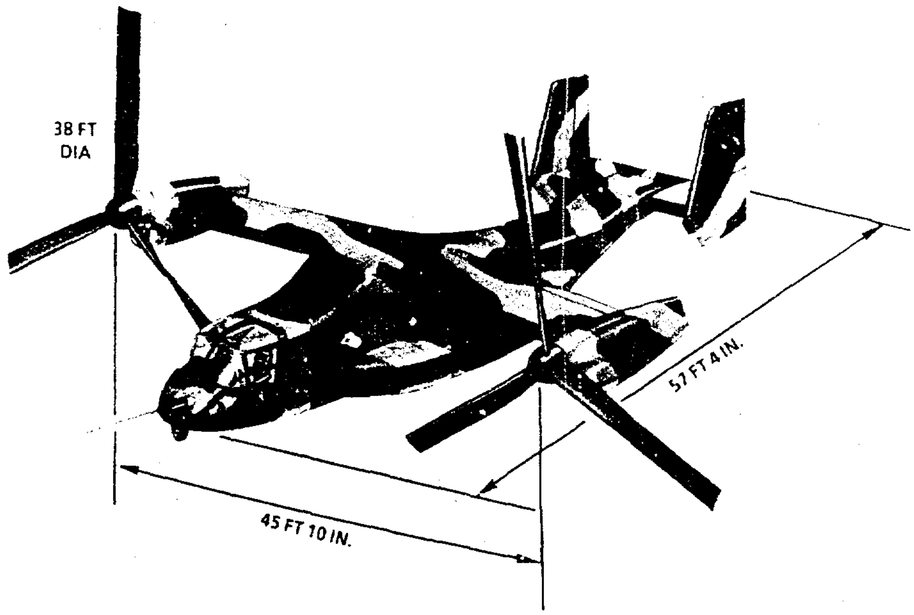

Figure 4. Overall Dimensions

Both the wing and fuselage are primarily composite structures. Sixty percent of the V-22 is carbon / epoxy and an additional 10 percent is fiberglass. This provides the V-22 with the significant advantages of composite structure: strength-to-weight ratio, non corrosion, good fatigue life and damage tolerance.

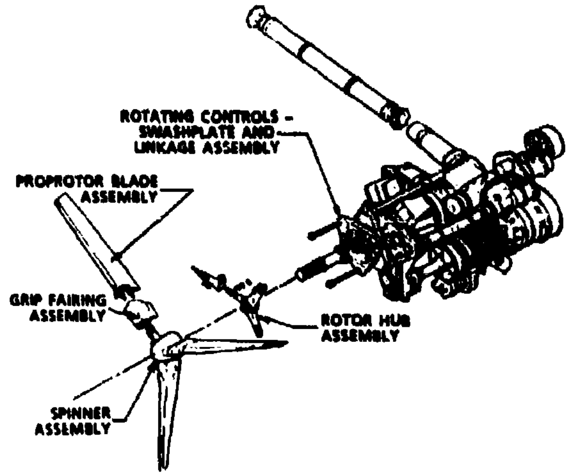

Figure 5. Rotor, Hub and Mechanical Controls

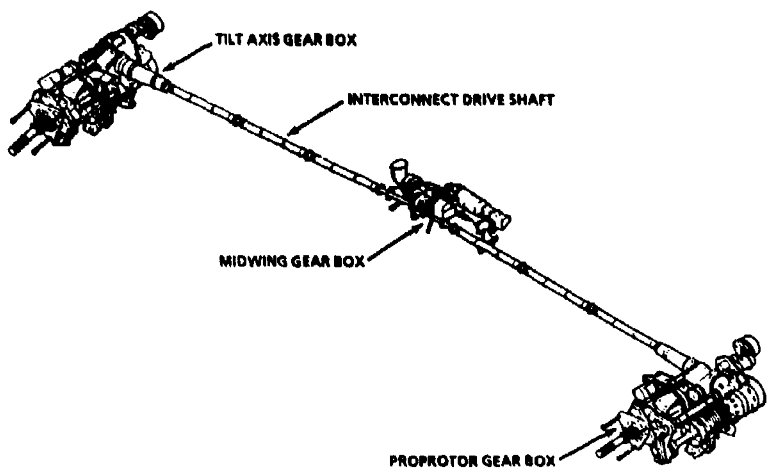

Figure 6. Power Train With Interconnect Drive Shaft

The V-22 flight control system is a digital triplex in-line self-monitored fly-by-wire design, as shown in Figure 7. The primary flight control system (PFCS) and automatic flight control system (AFCS) are separated to partition the flight critical functions from the mission and handling qualities enhancement functions as shown in Figure 8. During flight test development, an analog backup computer is provided to give dissimilar backup redundancy in case of a generic software fault in the digital system.

PERFORMANCE CHARACTERISTICS

The design configuration of the V-22 results in an aircraft with a unique combination of performance characteristics that provide the potential to perform a wide spectrum of missions. Key performance characteristics are as follows:

- Hover Gross Weight

  The hover out-of-ground effect gross weight capability of the V-22 at sea level standard is 47,800 lbs. At the USMC operating weight empty of 32,691 lbs., the useful load is 15,109 lbs. By increasing the tip speed from 789.5 feet per second to 820 feet per second, the useful load can be increased to 17,509 lbs.

- STOL

  With the rotors tilted forward, the V-22 has a short takeoff and landing capability that significantly increases the payload capacity, as shown in Figure 9. Optimum nacelle tilt to minimize the takeoff roll is 30 degrees from the vertical. In this configuration, the V-22 is designed for a takeoff gross weight of 60,500 lbs. This allows for a payload plus fuel capability of 27,800 lb or increased fuel capacity with additional fuel tanks in the cabin for self deployment.

- Payload-Range

  The payload-range capability of the V-22 is shown in Figure 10. The V-22 will have a payload-range capability three to four times greater than the CH-46, which it replaces in the U.S. Marine Corps. Mission speed will be twice that of today's conventional helicopter.

- **Altitude – Airspeed – g Envelope**

Figure 11 depicts the altitude airspeed potential provided by the V-22. The V-22 design provides for a 15,000 foot hover ceiling and a 28,000 foot service ceiling in airplane mode. Max level flight speed at sea level is 275 kts which provides a level flight true airspeed capability of 330 kts at 16,000 feet. The airspeed – g capability is shown in Figure 12 for the structural design gross weight of 39,500 lbs. The V-22 is designed for 4 g's at speeds up to the dive speed of 345 kts. The high maneuverability of the V-22 enhances its capability to perform assault and tactical missions as well as increasing evasive capability.

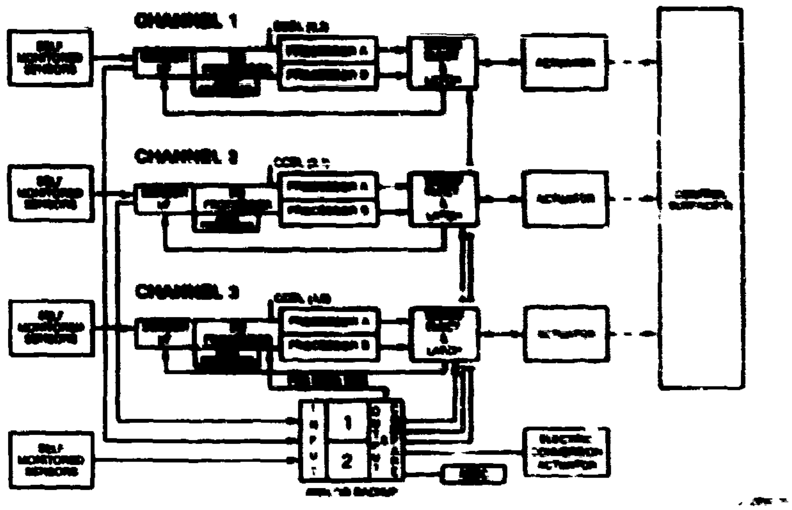

Figure 7. FCS Architecture

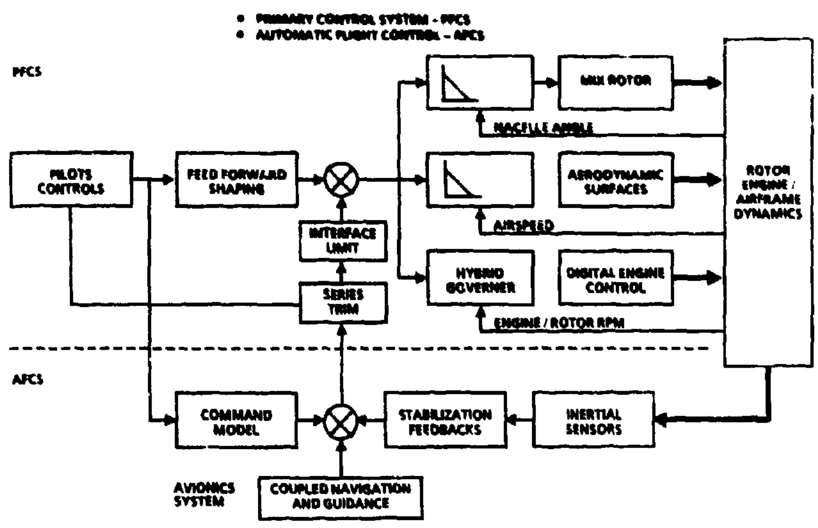

Figure 8. V-22 Flight Control Partitioning

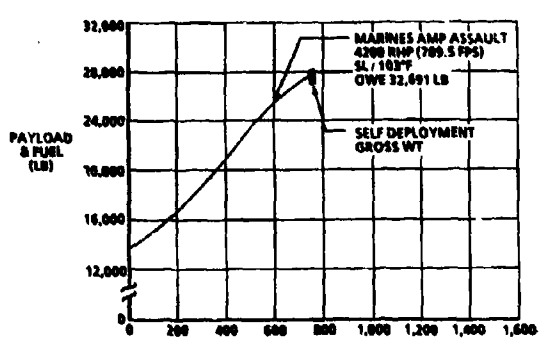

Figure 9. V-22 Payload Plus Fuel Capability With Short Takeoff

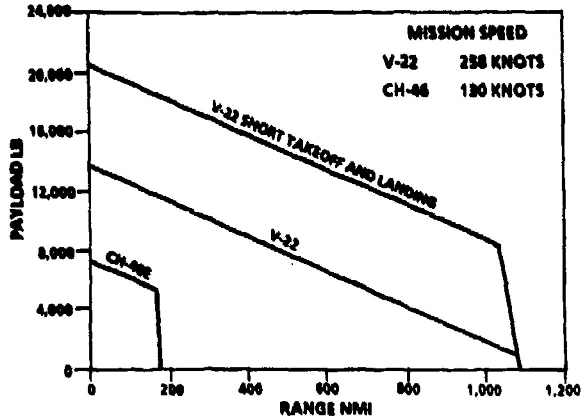

Figure 10. USMC Payload-Range Comparison

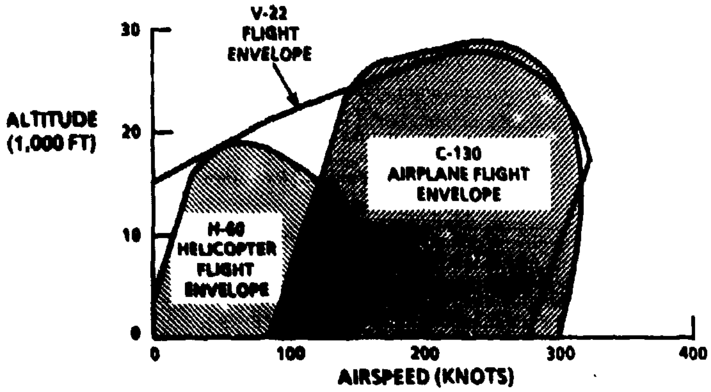

Figure 11. V-22 Altitude-Airspeed Envelope

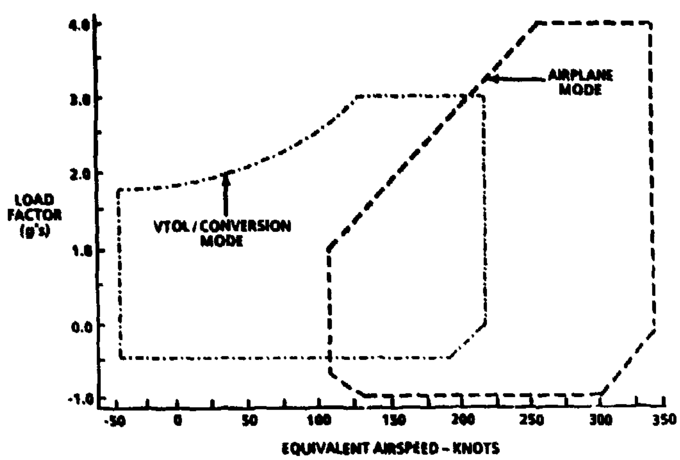

Figure 12. V-22 Airspeed-g Envelope

DESIGNED-IN CAPABILITIES

Integral to the configuration are key designed-in capabilities that enhance the potential of the V-22 to conduct a wide range of missions.

- **Shipboard Compatibility**

  A key design driver for the V-22 was shipboard compatibility. As shown in Figure 13, the general dimensions of the V-22 are driven by clearance requirements for taxi, takeoff, and landing on the LHA ship deck. An important design feature that enhances shipboard compatibility is turnover angle. The V-22 has a turnover angle of 28 degrees. This capability is made possible by the tricycle landing gear design and wide footprint of the main landing gear. On-deck operations of the V-22 in rough seas will be significantly enhanced. The V-22 has the capability to land on a ship deck that is moving .3 g's vertical, 3 degrees in pitch, and 15 degrees in roll with a 45 knot wind.

The aircraft is designed to fold compactly for efficient stowage aboard ship. The stowing sequence is shown in Figure 14. The rotor blades are folded inboard over the wing, nacelles are rotated to cruise mode, and the wing is then rotated clockwise 90 degrees. The entire sequence is accomplished in 90 seconds.

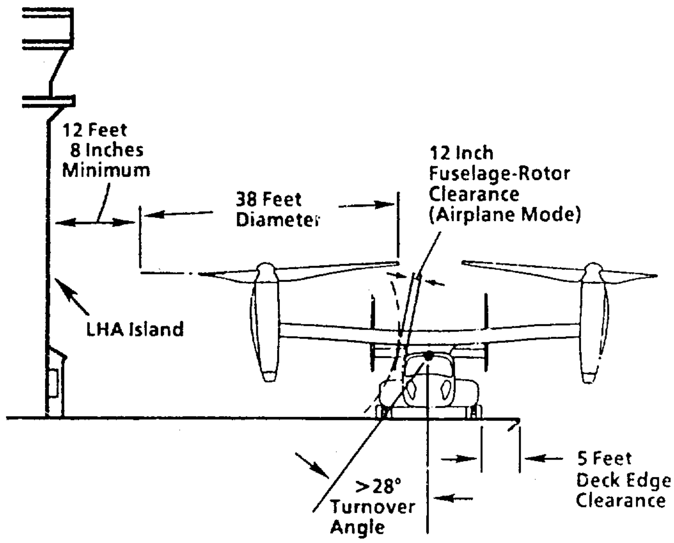

Figure 13. LHA Clearance Requirements

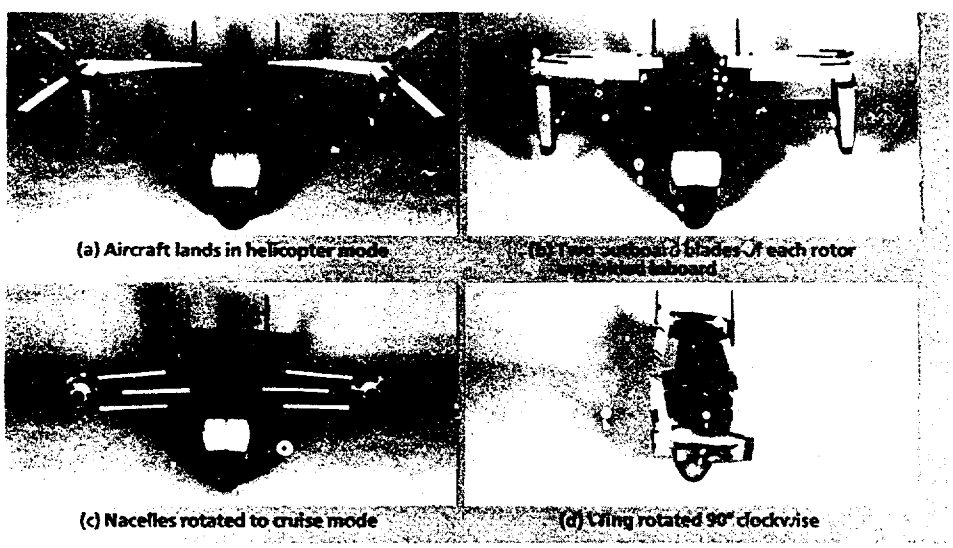

Figure 14. Wing Stow Sequence

- Self Deployment

The V-22 is designed for a self deployment capability of 2100 nautical miles. For the Marine self deployment mission, the fuel configuration is shown in Figure 15. Standard fuel capacity for the three sponson tanks and the two wing feeder tanks is 9,700 lbs Two internal palletized fuel tanks are added inside the cabin to provide a total fuel capacity of 26,234 lbs. With this fuel configuration, a short takeoff is accomplished at 60,500 lbs gross weight.

- In-Flight Refueling

The V-22 is designed with two types of in-flight refueling: air-to-air and hover. Figure 4 shows the refueling probe located on the nose of the aircraft. Air-to-air refueling can be accomplished at an average rate of 330 gallons per minute by the KC-130, KC-10 or other standard tanker aircraft. Hover in-flight refueling over land or ship deck is accomplished, as shown in Figure 16. The rescue hoist, which extends through the cabin side door, is used to haul the ground fuel line up into the cabin. The ground fuel line is then connected to the aircraft fuel system through an access port in the cabin for fuel transfer.

- High Speed External Load

The V-22 is designed to carry external loads faster than any of today's helicopters. A dual hook system is provided for a combined 15,000 lb load. Single hook capability is a 10,000 lb load. Examples of external load configurations are shown in Figure 17. For the Marines, a key external load for first wave assault is the HMMWV (high mobility multi-purpose wheeled vehicle). The V-22 has the installed power capability to carry the HMMWV to 215 kts and the HMMWV has been shown by wind tunnel test to be a stable load in a dual hook configuration at airspeeds higher than 215 kts. High speed carriage of the HMMWV will significantly enhance the Marines' first wave assault capability.

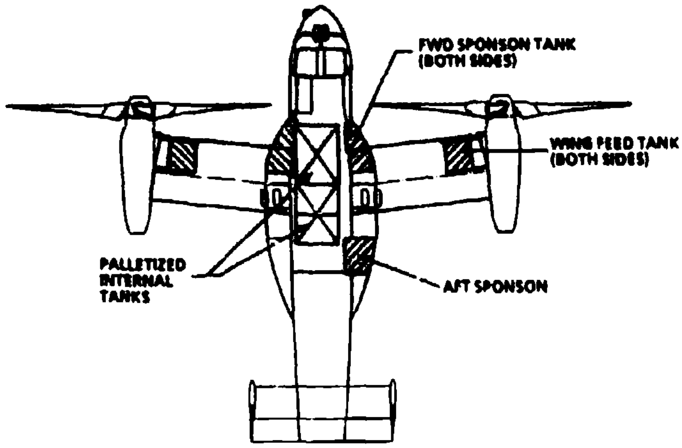

Figure 15. Fuel Configuration For USMC Self Deployment

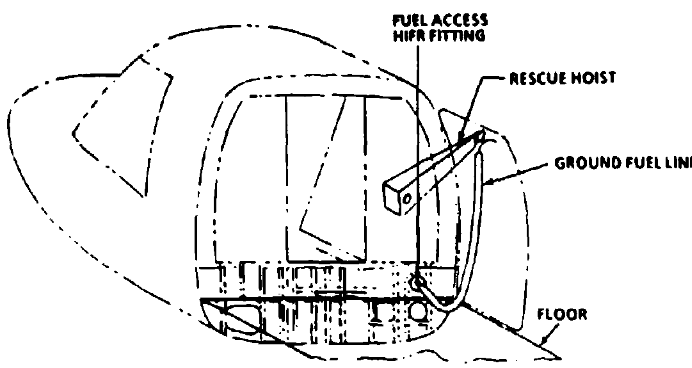

Figure16. Hover In Flight Refueling

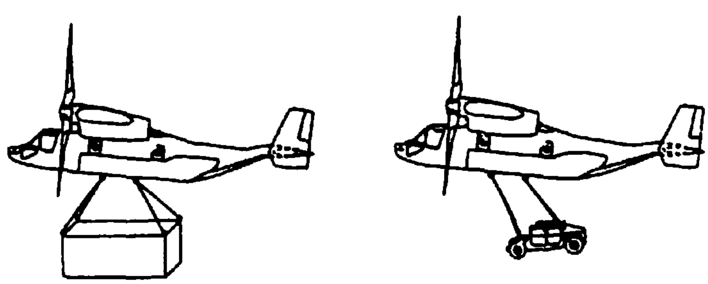

Figure 17. V-22 External Loads

- Crashworthiness

A key design element of the V-22 is the inherent crashworthy design. The aircraft is capable of withstanding a 24 fps vertical landing and remain intact. For landings with a higher descent velocity, the wings are designed to break off at the fuselage to relieve the force at impact. Both cockpit and cabin crew seats stroke to reduce passenger vertical g loading. The stroking seats provide a 14.5 g capability. In addition, the fuel system is designed with crashworthy fuel cells and the nose of the aircraft includes an anti plow bulkhead. For ditchings at sea, the V-22 has demonstrated an inherent buoyancy stability in Sea State 5 (8-12 foot seas). Figure 18 shows a model of the V-22 during ditching tests. Emergency egress is provided for both land and water landings via removable cockpit windows and cabin doors, hatches and windows.

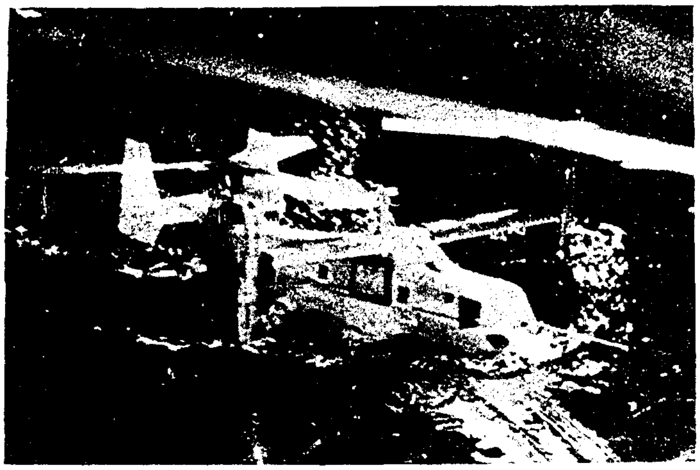

Figure 18. **Model of V-22 During Ditching Tests**

- Vulnerability

  A significant reduction in vulnerability is achieved on the V-22 by means of two methods systems protection and ballistic tolerance. The V-22 includes nuclear, biological, chemical NBC filtration as a part of the overall environmental control system. For E3 protection (electromagnetic interference, lightning, nuclear electromagnetic pulse), the V-22 has been designed through selection and application of materials and electronic and electrical systems design to perform satisfactorily in the worldwide modern electromagnetic environment. Additional protection for aircraft systems is provided by selective use of armor (pilot/copilot seats, swashplate actuators), redundancy, and system separation. For example, the hydraulic system is designed to operate with two failures by means of separated, redundant systems and control surface actuators. Ballistic tolerance on the V-22 is enhanced by the use of inerted fuel tanks, self sealing fuel bladders, hydraulic ram protection, halon engine fire suppression, and the extensive use of composites in the primary structure. The V-22 airframe is designed for HEI ballistic hits and will continue to fly safely up to limit load maneuvers. The V-22 is also designed to survive armor piercing rounds (API).

INTEGRATED COCKPIT AND AVIONICS

Designing an aircraft to satisfy the extremes of operator performance during both daytime and nighttime puts high demands on the cockpit designers. To meet these demands, the V-22 operational capabilities have been significantly enhanced through integration of all avionics and systems control via an all "glass cockpit". Emphasis has been placed upon using automation and the latest technologies in navigation, guidance and control to simplify tasks, reducing pilot workload to make the aircraft easier to fly, and stressing the pilot's role as mission manager. To accomplish this, the integrated cockpit and systems controls are task oriented rather than hardware oriented.

- Glass Cockpit

  The V-22 is the first military aircraft to complete a fully integrated "glass cockpit" (Figure 19). There are no dedicated gauges or instruments for display of aircraft data. The Cockpit Management System (CMS) is focused around four (4) color Multifunction Displays (MFDs) and two (2) Control Display Units (CDUs). The MFDs provide the primary interface with the aircraft, while the CDUs accommodate all required data entry tasks. Each high-resolution MFD utilizes a 6-inch by 6-inch usable display surface that is sunlight readable as well as fully Night Vision Goggle (NVG) compatible. The CDUs allow the operator to make all data entry through a single device, via dedicated function keys and a full alphanumeric keypad.

- Helmet Mounted Displays

  Another critical aspect of the V-22 Cockpit Management System (CMS) is the incorporation of two integrated Helmet Mounted Displays (HMDs). Each HMD will allow the operator to fly "heads-out" of the cockpit while displaying critical flight symbology, FLIR video, and Night Vision Goggle (NVG) imagery directly in front of his eyes. This unique capability allows for V-22 crews to perform all missions using head controlled sensor slewing and targeting, which enhances threat avoidance, rescue operations, and landing zone penetrations.

- Surveillance Capabilities

  The V-22 avionics suite includes a Forward Looking Infrared (FLIR) system to further compliment night operations. The FLIR supports low level flight, navigation, and target / survivor location. For the U.S. Navy Combat Search and Rescue (CSAR) and U.S. Air Force Special Operations Forces (SOF) missions, a Multifunction Radar provides navigation modes including terrain following / terrain avoidance (TF / TA) capabilities. Supplementing the sensor capabilities is a Digital Map reference system allowing the crew to continuously update their current position with pinpoint accuracy.

The use of these sensors, combined with the NVG capability afforded by an integrated helmet, dramatically increases the ability to fly low level missions at night with a minimum chance of detection, thereby assuring mission success.

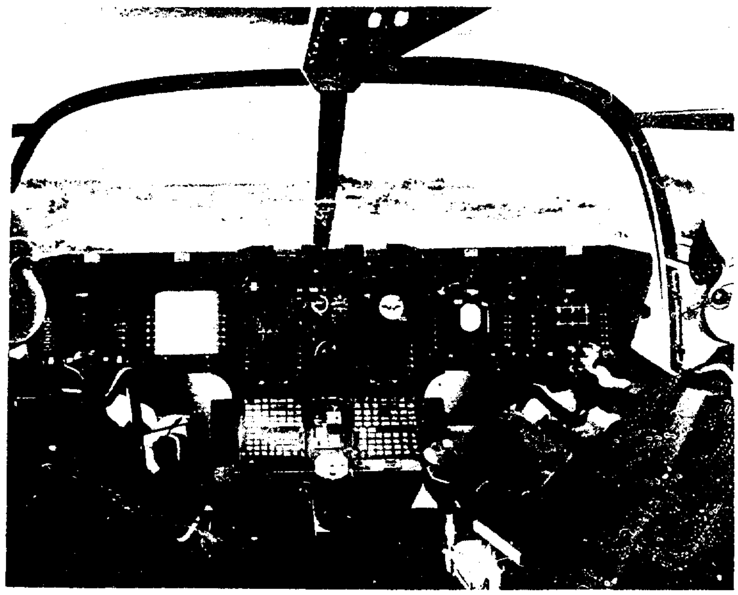

Figure 19. V-22 Cockpit

SUMMARY

The broad spectrum of operational capabilities make the V-22 Osprey a multi-mission aircraft with both land and ship based applications. The combination of performance characteristics (e.g., speed, range, payload, maneuverability) plus designed-in features (e.g., "glass cockpit," survivability) result in an aircraft capable of satisfying many mission requirements well into the 21st century.

REFERENCES

1. Martin, Jr., Stanley and Ostlund, Richard, "V-22 Developmental Status", presented at the American Helicopter Society Technical Specialists Meeting on Tactical V/STOL, New Bern, North Carolina, September, 1989.

2. Clark, R. D., and McAdams, G. A., "The V-22 Osprey from Concept to Fruition", presented at the Canadian Air and Space Institute in Montreal, June, 1988.

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TACTICAL SUPPORT EH101

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SUMMARY

The paper will review the development and use of military tactical helicopters from the early beginnings to the present day. It will then cover the background to the EH101 explaining the rationale of its design philosophy and the application of technology and equipments to meet the requirements of the late '90s and the early 21st Century. Finally the paper will address the operational capabilities and applications of the EH101 related to a changing fast-moving battlefield environment. ~~(Ref. 1)~~

(25) * Helicopters, * Military aircraft.

MILITARY ROTARY WING DEVELOPMENT

During the 1930's and 40's rotary wing aircraft developed slowly with only tentative use by the military of autogiros and helicopters.

In 1950 the Korean War commenced and the US Military employed several hundred Bell H-13 helicopters as they policed the war zone on behalf of the United Nations. This initial force of helicopters was soon joined by hundreds of the larger Sikorsky H-19's and Piasecki H-21's undertaking the role of support vehicles replacing trucks, jeeps and ambulances in a road-poor terrain. Little was done at this time to arm helicopters as they often only had marginal performance to start with but their success in the roles they did carry out changed the tactics and strategy of land warfare forever.

The British used helicopters during operations in Cyprus, Kenya and Malaya where less than ideal hot, moist conditions provided the opportunity to learn a great deal about operating parameters.

The French developed helicopter tactics to a level not seen before during their involvement in Algeria and as well as employing the vehicles in support roles some where armed with guns and rockets to make them into offensive aircraft.

Technical development, particularly in turboshaft engines, facilitated further change to helicopter tactics which was applied during the Vietnam conflict. Greater payload and improved performance was now available and with the need for the suppression from the air of the Viet Cong who could take effective cover in the natural foliage of the jungles and fields, some of the Bell HU-1 Huey helicopters were equipped with guns and rockets.

It was at this time that military commanders called for helicopters to be designed to meet specific roles. The Bell UH-1 was developed to become the AH-1 Huey Cobra and since then the concept of attack helicopter has led to the McDonnell Douglas Apache in the West and the Mi-24 in the Soviet bloc countries. (Ref. 2)

Logistic support helicopters have moved on from the Bell H-13 to custom build aircraft designed to lift very large loads, accepting internally up to 45 troops, vehicles or palletised freight as well as retaining the agility and survivability so necessary when entering active battlefield zones.

EH101 BACKGROUND

In the late 1970's the British and Italian Governments concluded studies on the type of helicopter that would be required to replace the aging Westland Sea King's and Agusta SH3D's for both their Navies. These studies showed the need for a larger helicopter with increased range, payload and overall operational capability. The two Governments also recognised that the development of a new helicopter was a significant event in terms of cost and investment and required that the resulting vehicle had the widest possible application.

In 1979 Great Britain and Italy, in conjunction with Agusta and Westland, signed a bilateral memorandum of understanding to jointly undertake a feasibility study of the design, development and manufacture of the next generation of Anti-Submarine Warfare (ASW) helicopters. In 1980 the two companies formed a jointly owned Company, European Helicopter Industries', (EHI) to undertake the management of the project. The two companies through EHI also initiated an extensive market research activity to establish if markets existed for a 13,600kg (30,000lb) class helicopter. Desk work combined with a large number of visits to defence and civil operators in many parts of the world resulted in the confirmation that there was a substantial market for an export military utility and commercial version of such an aircraft.

Therefore, from these varied requirements, EH101 (Fig. 1) was born resulting in the helicopter being the first to be developed jointly for military and commercial operations from the outset.

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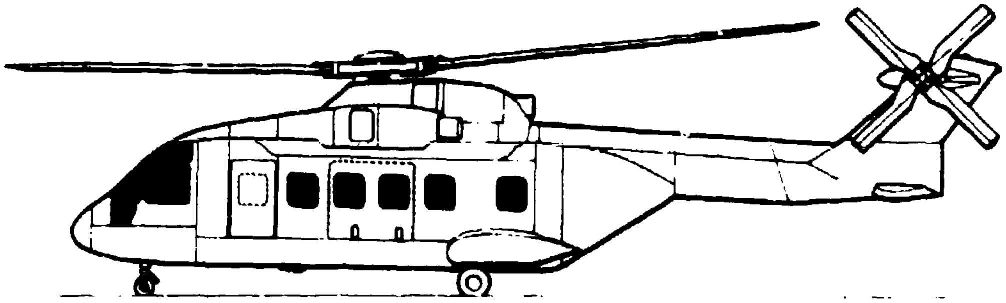

Fig 1 EH101

DESIGN PHILOSOPHY

To design a helicopter to meet the demanding and dissimilar roles of a naval ASW vehicle, a battlefield tactical helicopter and a civilian passenger variant called for optimisation. Therefore, trade-off studies between variants were undertaken in order to establish those variant requirements which matched and those which called for a compromise.

The sizing of the vehicle had to be consistent with small ship operations and therefore similar in external dimensions to the vehicles it was to replace. At the same time, increased cabin size was needed to house additional equipment essential to achieve the naval mission requirements, namely, of being completely autonomous with respect to the ability to collate and analyse data received by the acoustic sensors, as well as locate, target and destroy enemy submarines. This resulted in a helicopter with an overall length of 22.8m (75 feet) and 15.8m (52 feet) with the rotors and tail section folded for shipboard stowage. For comparison, the Sea King is 22.0m (72 feet 8 inches) long and 14.4m (47 feet 3 inches) long with blades and tail section folded. The cabin of the EH101 is 6.4m (21 feet) long and almost 2.4m (8 feet) wide, a floor area which provides ample room for mission equipment packages and personnel. The large cabin is attractive from a passenger/troop carrying point of view and will allow the EH101 to carry 30 passengers in airline comfort in the civil variant and up to 35 seated troops in the utility variant which incorporates a rear loading ramp.

The initial issues of main rotor design were between the need for small ship operations requiring agility and the need for low vibration. The result was a 5-bladed fully articulated rotor hub with a 5% hinge offset. The 5% hinge offset, which is high for an aircraft of its class, also satisfies the utility variant need for agility, particularly whilst nap of the earth (NOE) flying. Tip speed was next considered and here weight, blade area and transmission torque levels were in conflict with noise. The problem was resolved largely in favour of rotor noise, thereby satisfying both civil noise legislation and reducing battlefield signature for the utility variant.

The main rotor blades on the EH101 were derived from the British Experimental Rotor Programme, involving Westland and the Royal Aircraft Establishments (RAE) at Bedford and Farnborough.

The availability of powerful computer aided design facilities, the advent of composite blades, and the perfection of moulding techniques enabled the designers to use optimum distributed aerofoil sections and a novel tip design to produce a more efficient rotor blade. The two old enemies to high forward speed in helicopters, retreating blade stall and advancing blade compressibility effects, have been pushed further back by using an efficient thicker, reflex cambered section on the inboard part of the blade, and a thinner aft loaded section outboard which has better high speed capabilities. The inboard reflex camber effectively counters the pitching moment produced by the outer aft loaded section. The tip itself is also thin, and overcomes high Mach number problems by using the familiar technique of sweep back. In fact the outboard sweep uses the shape familiar from Concorde. Just sweeping back the tip would put the centre of pressure too far aft, giving imbalance of both mass and lift at the tip, so a forward stagger was evolved to overcome this.

By careful design, this also provided a notch, which acts like a wing fence, isolating the flow either side of it. The controlled vortex thus generated at the tip softens retreating blade stall, thus making penetration into the stall regime less onerous from the load and handling viewpoint.

At high forward speed the design increases rotor lift by about 30% (in comparison with a conventional blade of similar chord and length) and significantly reduces noise and vibration.

Final main rotor design requirements centred about the three variants performance needs. For naval requirements, a good hover performance was needed with low speed considerations but high engine failure safety margins (flyaway ability), this being critical for dipping sonar operations. The utility variant called for the same transmission capability as the naval but needed a substantial increase in installed power to satisfy the hover design point for the mission take-off performance. The requirement for good flyaway ability was also needed by the utility variant for NOE flying. In power terms the civil version was dependent on an uprated transmission system when compared with the naval version. Since it also had to deal with a more onerous hover environment than the naval, the engine requirement was seen as being consistent with the needs of the utility variant. The result of integrating the needs of the three variants produced the following:

- Rotor diameter — 18.6m (61 feet)
- Number of blades — 5
- Tip speed — 204 m/s (670 ft/sec)
- Transmission — 3879 KW (5200 shp)
- Engines:
  - naval — 3 x GE T700-401
  - utility/civil — 3 x GE CT7-6
- Blade de-icing

The tail rotor of the EH101 was designed to provide the naval variant with the ability to hold heading in adverse wind states, at maximum mission weight with good pedal margins plus the agility to operate from the confined decks of small ships in high sea states. In addition, the noise signature was minimised to a level compatible with the main rotor external noise and compliant with the civil requirements. Tail rotor data is as follows:

- Rotor diameter — 4.0m (13 feet 2 inches)
- Number of blades — 4
- Tip Speed — 198m/s (650 ft/sec)
- Blade anti-icing

With the requirements of the integrated programme firmly established, a review was conducted of the various regulatory documents involving the civil and military authorities in the UK and USA. This covered both design and testing and resulted in a defined single standard for the EH101 covering the requirements of AVP 970, MIL SPECS, BCAR and FAR. The resultant document therefore, defined the common philosphy around which the military qualification and civil certification will be based.

At all times, however, the design philosphy sought to seek improvements in:

- Performance
- Safety and Survivability
- Operating Costs
- Reliability and Maintainability
- Operational Capability

This was to be achieved through the application of:

- 3 engines and higher power margins
- Advanced rotor technology
- Damage tolerant airframe and dynamic structure
- Greater system redundancy
- On board health monitoring systems
- Advanced avionics

BATTLEFIELD SCENARIO

No matter how fast, agile, adept at load carrying or effective in dispensing fire power a helicopter is, it can never hold ground. The purpose of a helicopter in a battlefield environment is to act in concert with ground troops and ensure that air fire support, troop reinforcement and the delivery of supplies are at the right place at the right time.

The Soviet forces employ three main tactics in order to advance their armies. Encirclement, the exploitation of weak points or the straight forward frontal attack. The exploitation of weak points such as the boundaries between two nationalities' armies or the deployment of operational manoeuvre groups (OMGs) who, via helicopters, pass over the front line of own troops (FLOT) in order to seize and hold ground until relieved by their own troops (Ref. 3) requires NATO forces to have on call agile, large load carrying helicopters, like the EH101, to transport troops and freight in order to repulse such actions.

The initial identification and subsequent tracking of the Soviet FLOT is likely to be difficult due to the high mobility doctrine adopted by the Warsaw Pact countries. Support helicopters must therefore expect to find themselves operating close to enemy forces and to receive fire from unexpected encounters.

Avoiding Detection

The best defence is to remain undetected which calls upon the highest level of piloting skill to use effective ground cover and on an aircraft to be capable of operating at low level, with low signature, at night and in poor weather.

If detected, ASE (aircraft survivability equipment) can offer protection but the aircraft must also be as agile as possible to avoid being hit. If hit, it must be able to absorb damage and keep flying, and if brought down, the crew and passengers need the best chance of survival.

For the majority of missions, the large cabin of the EH101 will comfortably house the payload to be airlifted, thereby precluding the need for an underslung load. This increases the speed of the aircraft from 95 knots with an external load to its normal cruise speed of 150 knots as well as allowing the vehicle to travel NOE (nap of the earth). The combination of these factors with the 5% hinge offset incorporated in the main rotor hub and the relieving of the pilot's work load through the automatic flight control system (AFCS), which allows more pilot attention to be given to external events, makes the EH101 a far more difficult target for radar acquisition devices to pick up or for manually directed fire to be effective. The EH101 can also avoid detection by deploying in poor weather as well as at night as the aircraft will be NVG compatible.

The noise signature is low and unobtrusive for the size of the aircraft thanks to the relatively low blade tip speeds.

Slow blade rotation speeds on the EH101 help to minimise leading edge signature. (Ref.4)

BATTLE HARDNESS

Once detected, there are a number of devices available which either warn the pilot of an impending threat and/or disrupt hostile missiles. Jammers, some of which employ pulsed heat radiation to confuse missiles whilst others detect and then call upon Chaff or Flare to protect the helicopter, are optional fits to the EH101, as are Hostile Fire Indicators, Laser Warning Receivers and other Electronic Counter/ Surveillance Measures.

The aircraft has been designed to sustain a certain degree of ballistic damage. This is achieved through the application of greater system redundancy and damage tolerant airframe and dynamic structures. In addition, the crew seats as well as many of the critical system areas can be armoured or shielded.

Structures

The forward fuselage is made up of a traditional light alloy underfloor construction with a fully composite glazing structure, the latter capable of withstanding a 1.8Kg (4lb) bird strike at 150 knots. The cabin section consists of precision machined aluminium lithium frames with aluminium honeycomb sandwich skin panels.

The structure is a careful blend of traditional light alloy construction and the use of composite materials where they given a significant advantage.

The gearbox and engine fairings and cowlings are all composite. Tests show that composites have better characteristics in respect to operation in a high frequency environment, in particular their slow crack propagation rates and fail safe characteristics.

Multiple load path philosophy is incorporated throughout the structure. The upper structure is designed with significant fore and aft members joining the main lift frames, but also continuing both forward and aft to the adjacent frames as shown in Fig. 2. This permits significant vertical loading to be beamed to the adjacent frames should the primary lift frames receive ballistic damage and fail.

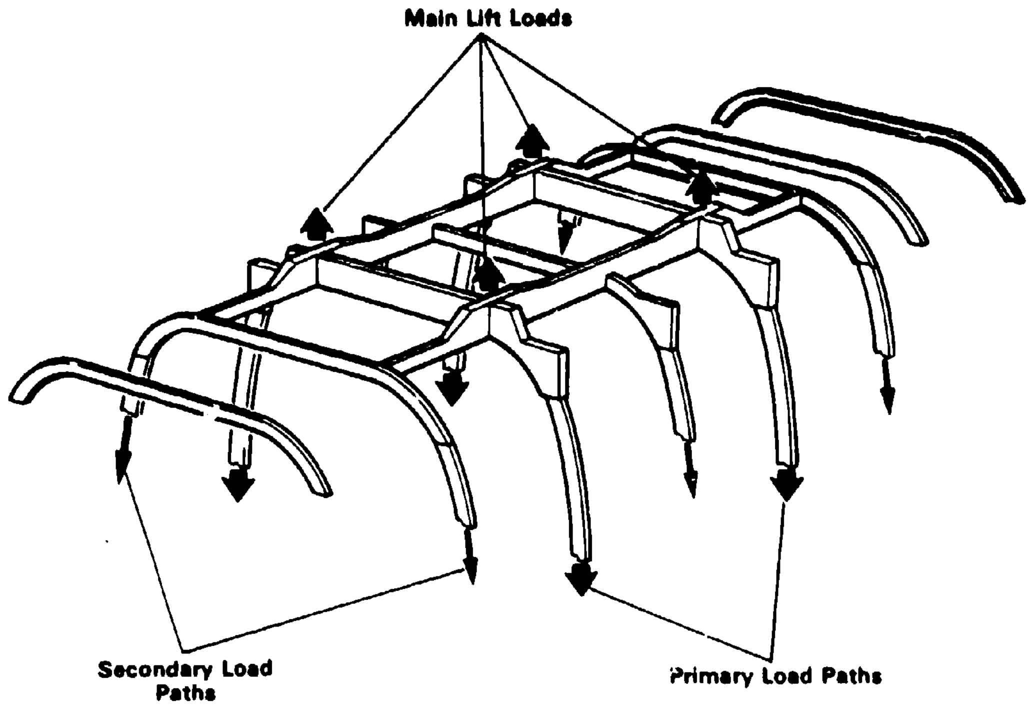

Fig. 2 - Airframe Load Path Redundancy

Power Plant

The EH101 is equipped with three engines plus an APU, providing considerable redundancy in terms of safe continued flight following an engine failure. Layout of the engines has been carefully chosen to avoid simultaneous damage. In the unlikely event of an uncontrolled power turbine failure, the disc burst line does not impinge on an adjacent engine. A single engine failure over the battlefield would not call for the mission to be aborted nor prevent NOE flying thus improving survivability.

Dynamics

The main rotor head design provides for improved structural integrity through the series of rings made up from unidirectional windings which forms the two composite plate structures attached to a metallic core. There are five inner rings with a single outer ring around the inner rings. In the event of a failure of the outer ring, the centrifugal loads can be taken through the inner smaller rings associated with each blade position, into the central metal hub as shown in Fig. 3. Each load path is strong enough on its own to carry the centrifugal loads. The elastomeric centering bearing at the end of each metallic arm, where the blades are focused at a 5% hinge offset, allows flap, lag and torsional movement. This is also the normal path for lift and out of plane loads through the arms into the core. Should there be a failure of a lift arm, the lift loads from the blades come into the main elastomeric bearing for the blade. The elastomeric is mounted at the outer junction of the two composite plates, which effectively forms an 'A' frame to take the lift loads back into the hub. The design has produced a structure which is reliable, easy to maintain and whose condition can be assessed by inspection and if a failure does occur in service, the result is a minor inconvenience rather than a major disaster.

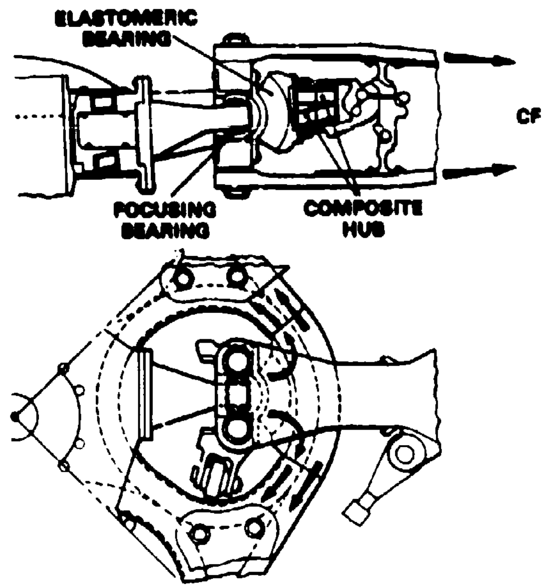

Fig. 3 Main Rotor Head

Load path redundancy applies also to the blade attachment bolts as shown in Fig. 4. The primary shear loading is normally carried out by the outer sleeve but should this fail, the retaining bolt is capable of transmitting the load into the outer tension link.

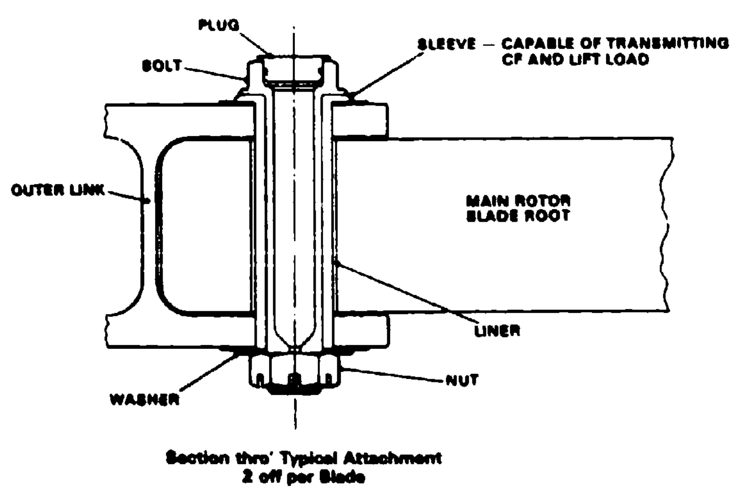

Fig. 4 Main Blade Attachment

Hydraulics

The hydraulic system is made up of three independent integrated hydraulic power supplies, two of which normally supply the duplexed flight control servo jacks, while the third circuit supplies the auxiliary services. The advantages of a third system which can if necessary power the main and tail flying controls are that the probability of being reduced to a single hydraulic system is lowered from 3 x 10 - 4 (Reasonably Probable) to 2 x 10 - 8 (Extremely Remote) and is much more typical of fixed wing flying controls. There is a high degree of separation of the three systems to minimise multiple failures and battle damage.

Fuel

Fuel, under normal conditions, is supplied to the three engines from their own dedicated tanks by duplex AC electrical booster pumps. In the event of a failure, the electrically operated crossfeed manifold enables any engine to be fed by any pump or tank. The integrity of the fuel supply is further enhanced by the fuel suction capability of the engines.

The self-sealing fuel tanks, designed to accept penetration of up to a 12.7mm (1/2 inch) tumbled round, are housed in individual main cabin underfloor strengthened bays with little side elevation exposure.

Transmission

The main gearbox, as with all helicopter transmission systems, has a number of single load path configurations which cannot be duplicated. With the EH101 gearbox, four vertically mounted struts accept all shear and moment loads and in the event of a single strut failure, the remaining three struts accept the redistributed loads. The torque reaction is taken directly into the aircraft structure at the cross-members of the lift frames by a four horizontal strut reaction system which places the struts in compression. Again these are sized to react to the redistributed loads following a single strut failure.

Therefore the gearbox casing only has to transmit torque reactions and not the full reaction associated with lift, as with the more conventional footed gearbox. In addition the gearbox casing weight is substantially reduced because its role permits a thin wall configuration.

The gearbox also has two independent lubrication circuits, each with self-contained pumps, sumps and filters. No external piping is present, thereby reducing the risk of ballistic damage. Should there be a loss of lubricating fluid, the gearbox has the capability to run for at least 30 minutes.

Electrical

The electrical system has been designed to provide a power distribution system which is flexible and failure tolerant, with a totally independent emergency back-up which is not subject to a time limitation. Main power is derived from two generators, one mounted on the drive from the main rotor gearbox and the second is driven by the accessory gearbox. A third lower rated generator is provided for emergency service and is driven from the APU. The electrical system thus provides two independent main channels each capable of maintaining the total system with reversion for the essential supplies to the emergency generator.

Flight Control System

The Automatic Flight Control System is designed to allow single Pilot IFR operations to be carried out. The AFCS design is such that the basic auto stabilisation modes on first failure calls for no pilot action. The less critical ASE functions and the Autopilot modes will achieve a 6-second intervention time on first failure. All facilities will meet a 3.5 second intervention time on second failure. Other redundancy features are: ASE Implementation is by duplexed series actuators inserted between the pilot and the primary mechanical mixing so that axis segregation is maintained. Auto-pilot functions and control trimming are provided by a simplex parallel actuator on each axis. The AFCS architecture features two separate identical digital computer units, each of which have four micro-processors, two of one type and two of a dissimilar type, with software also being dual sourced; duo-dual sourcing of this type reduces the possibility of a common mode failure to the system. The mechanical controls have duplicated large diameter (mostly 40mm) control rods which are protected by structure.

Crashworthiness

Accepting all the measures taken to prevent a forced landing, such as system redundancy, the employment of threat warning devices, piloting skills to avoid hostile fire and the use of damage tolerant materials, a forced landing may still occur. The EH101 has therefore been designed to have a high energy absorbing undercarriage and structure.

The level selected for the EH101 is the 85th percentile survivable crash as defined in the American Crash Survivable Design Guide, which means that using nominal energy absorbing seats, 0.3m (12 inch seat stroke), the occupants can survive a vertical velocity of descent of 10m/s (33.5ft/sec).

The undercarriage is designed to withstand vertical rates of descent of 3.66m/s (12 ft/sec) without any deformation to the undercarriage or fuselage structure. In the event of a descent rate in excess of 3.66m/s (12 ft.sec), the undercarriage is designed to prevent hydraulic locking, thereby allowing for maximum vertical energy absorption by the undercarriage before the forces are transmitted to the fuselage structure. Eventually, the fuselage will contact the ground and, finally, the 100mm. (4in) of crushable structure beneath the fuel tank floors will deform, absorbing impact energy. The EH101's fuselage employs aluminium lithium frames because the material is a good absorber of impact energy. The fuselage is shaped to prevent ploughing, and as protection for the occupants the side walls buckle outwards, whilst the cockpit is designed to prevent injury to the crew from splinter fragmentation. The main landing gear has been located outside of the cabin area, thereby avoiding the penetration of the passenger space or the fuel system under crash conditions.

The fuel system is also designed to provide an improved standard of crashworthiness. The fuel system incorporates self-sealing, crashworthy tanks, break-away fillers and self-sealing frangible couplings. In a crash condition, provision of cross-over fuel vents ensure there is no fuel syphoning in the event of a roll-over.

OPERATIONAL CAPABILITY

The majority of nations, if not all, when considering the procurement of a new tactical support helicopter are driven by the need for a multi-role vehicle which, accepting the inevitable compromises, will successfully achieve the majority of their operational requirements. This multi-role concept was an initial consideration when planning the utility version.

The large cabin with access from a front port airstair door, a large centrally located starboard sliding door and the cabin width rear ramp provides a variety of loading/unloading options.

Tactical Troop Lift

Various configurations are possible: 30 fully equipped troops complete with four anti-tank Milan posts and 16 rounds can be seated or up to 45 lightly armed troops sitting on the floor with the seats removed. Loading and unloading trials have taken place with 30 fully armed troops; entry and exit times were 2 minutes and 40 seconds respectively. This rapid unloading is accomplished by using the rear ramp and minimises the time spent on the ground, therefore, greatly improving the survivability of the helicopter and cargo.

Logistic Support

Supplies can be taken direct from the rear area supply depots to the edge of the battlefield. The large floor area of the cabin combined with the 1.85metre (6ft 1 inch) headroom gives a volume of 28 cubic metres. The EH101 can accept two Landrover size vehicles or any mix of loads, for example, one vehicle, eight soldiers, plus freight - (Fig. 5). The large cabin allows for the movement of troops/stores whilst allowing the aircraft to retain its natural agility, high cruise speed and 'nap of the earth' flight capability, all essential requirements because it is inevitable that in its logistic support role the EH101 will have to operate some of the time in a hostile environment.

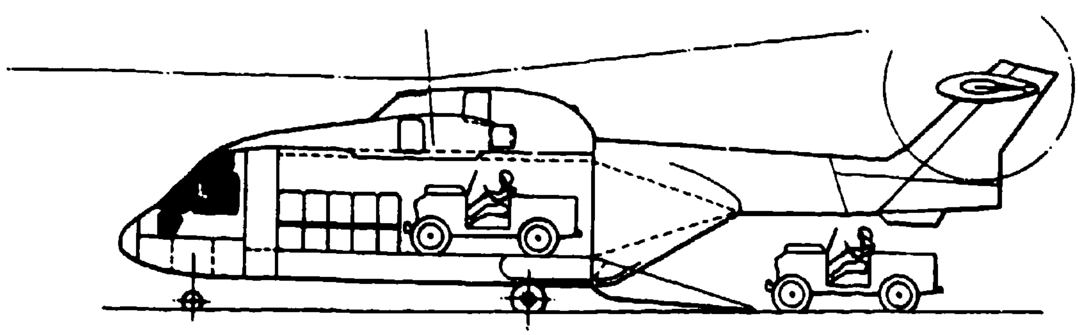

Fig. 5 Typical EH101 Mixed Load

Underslung loads can be carried via a crane hook, the maximum carrying potential of the helicopter being 5440Kg (12,000lb). The speed for such operations is 95 kts and when combined with the necessary pedestrian flight pattern the helicopter becomes more vulnerable to enemy fire than when in a clean condition. Such activities are best carried out in the lower risk areas of the battlefield.

Casualty Evacuation

On the battlefield area, a vital role is the 'Casevac' or casualty evacuation. The high speed transfer of wounded front-line soldiers to life-saving facilties is recognised as a valuable morale raiser. The ability to rapidly load stretchers through the large rear ramp minimises the time on the ground and once airborne, at 150 knots the EH101 can carry 16 litters and a five-man crew, together with full medical equipment, at a range of 500 nautical miles.

Range and Performance

Examples of the EH101 range and performance for varying applications of role are as follows and are based on a speed of 150 knots for internal loads at an altitude of 500m AMSL under ISA conditions with a radius of action of 75 nautical miles:

30 troops at 130Kg each	:	2 round trips without refuelling
Internal freight of 4536Kg	:	1 round trip without refuelling
Landrover and trailer at 2375Kg 2 drivers at 220Kg. and freight at 1941Kg	:	1 round trip without refuelling
16 stretcher patients	:	2 round trips without refuelling

Availability

The operational availability of the EH101 has been enhanced through the inclusion of a number of high technology features.

The EH101 is unique in that a Health and Usage Monitoring (HUM) system has been developed concurrently with the airframe, dynamic and avionic systems. The EH101's HUM system is the most advanced system yet incorporated into a helicopter, providing real time stored information not only from transmission but also from engines and critical components, working toward "on-condition" maintenance and lower operating costs. The application of "on-condition" maintenance will reduce downtime by not having to carry out what is effectively unnecessary maintenance. HUM itself will also reduce maintenance time as the system will enable faults to be isolated quickly to line replacement unit (LRU) level.

Operational sorties may be called for during poor weather or at night; however, the need to maintain tactical flight patterns under such conditions remain thereby increasing the risk of the mission. The design of the EH101 has sought to redress these problems. The helicopter carries full anti and de-icing systems, thereby overcoming the severe weather icing conditions encountered in the northern or mountainous areas of Europe. Navigational aids such as Global Positioning Systems (GPS), Terrain Reference Navigational Systems and Digital Maps can be integrated into the EH101 to provide 24-hour all weather pin-point navigation around the battlefield area. Night time flying in particular will be enhanced by the application of a Night Vision Goggle (NVG) compatible cockpit. The combination of all these aids to poor weather and night time flying improves the availability and effectiveness of the EH101 to a level not seen before in tactical support helicopters.

CONCLUSION

The recent developments in Europe concerning the changes of controlling authorities in Soviet satellite countries and the initiatives taken by Mr. Gorbachev to reduce the number of arms to be deployed in the future, has brought about much debate and radical re-thinking.

Whilst pursuing and supporting these new and welcomed developments and at the same time ensuring the continued safety of our nations against any aggressor, the helicopter is likely to play an even more vital role than is seen today.

A reduction of troops in Europe calls for those that remain to be more effective than at present which in turn requires that they are more mobile and it is here that the EH101 will play its role. Battlefield Commanders will have at their disposal a vehicle which is fast, agile and capable of transporting large numbers of troops and/or freight to repulse hostile actions.

Designed for exactly this role, the philosophy applied to the EH101 from its inception has been to provide three engine safety, advanced avionic systems, increased redundancy and greater survivability. All of these things have resulted in a rotorcraft capable of providing safe NOE, day or night all weather flying with a rapid response to role changes.

The EH101 Utility variant is the ideal airmobile tactical support helicopter for the 1990's and beyond.

References:

(1) Fielding J.C. - EH101 Operational Applications on the Future Battlefield; NATO DRG Seminar 89.

(2) Prouty R.W. - Military Helicopter, Design Technology.

(3) Gaines M. - Airmobility; Flight International No. 4153 Vol. 135, 25th February 1989

(4) Moyle J. - Survival of the Fittest; Defence Helicopter World Vol. 9, No. 1, Feb.-Mar. 1990

I am indebted to many colleagues at Westland, Agusta and EHI for their assistance and for the use of existing documentation within the companies.

REPORT DOCUMENTATION PAGE			
1. Recipient's Reference	**2. Originator's Reference** AGARD-CP-495	**3. Further Reference** ISBN 92-835-0585-9	**4. Security Classification of Document** UNCLASSIFIED
5. Originator	Advisory Group for Aerospace Research and Development North Atlantic Treaty Organization 7 rue Ancelle, 92200 Neuilly sur Seine, France		
6. Title	PROGRESS IN MILITARY AIRLIFT		
7. Presented at	the Flight Mechanics Panel Symposium held in Lisbon, Portugal, from 28th to 31st May 1990.		
8. Author(s)/Editor(s)	Various		**9. Date** December 1990
10. Author's/Editor's Address	Various		**11. Pages** 312
12. Distribution Statement	This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.		

13. Keywords/Descriptors

Military aircraft	Flight crews
Transport aircraft	Design
Air transportation	Aviation fuels
Requirements	Aircraft engines
Cockpits	

14. Abstract

These proceedings contain the papers presented at the AGARD Flight Mechanics Panel Symposium on Progress in Military Airlift held in Lisbon, Portugal from 28th to 31st May 1990.

Although military transport aircraft and helicopters will continue to be of increasing importance in future military operations, military transport aircraft technology has not received the same level of attention that has been directed, for example, to combat aircraft. In-service fleets of transport aircraft are also becoming physically old and technically outdated, and are less and less capable of fulfilling the more demanding mission requirements.

It was therefore important and timely to review the area of military airlift and assess: the present and perceived future military roles and requirements; the required developments in technology; the extent to which civil technology applications can enhance capability; technologies for real cost reduction; and to what extent the current and future development programmes in this field embody the new technologies.

The Symposium included sessions on operational experience and requirements; cockpit design and aircrew performance; specific technologies such as fuel, powerplant and aerodynamic design; and a review of current and new programmes.

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ISBN 92-835-0585-9